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PARTIAL CONTENTS

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IGR TRANSLITERATION OF RUSSIAN

The AGI Translation Office has adopted the essential features of Cyrillic transliteration recommended by the U. S Department of the Interior, Board on Geographic Names, Washington D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Office recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь Customary usage calls for "ie" in many names, e. g., SOVIET KIEV, DNIEPER, etc.; or "ye", e. g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".
2. Omitted if preceding a "y", for example, Arkhangelsky (not "iy"; not "ii").
3. Generally omitted.

NOTE: Well-known place and personal names that have wide acceptance will be used. Some translations may include elements of previous German transliteration from the Russian; this occurs in IGR most commonly in maps and lists of references. The reader's attention is called to the following variations between German and English systems which may cause confusion when trying to check back to original Russian sources.

German	English
w	v
s	z
ch	kh
tz	ts
tsch	ch
sch	sh
schtsch	shch
ja	ya
ju	yu

TENTATIVE CONTENTS FOR THE JANUARY 1960 ISSUE

FORMATION OF RESIDUAL MAGNETIZATION AND ITS DISTRIBUTION IN ROCKS[1]

by

G. K. Kuzhelov and Z. A. Krutikhovskaya[2]

• *translated by Paul T. Broneer, R & R Inc.* •

ABSTRACT

The result of residual magnetization investigation in the gabbroids of Volyn and the ferruginous quartzites of the Kremenchug anomaly as well as some other metamorphic rocks of the Ukrainian crystalline shield are considered. All the intensely magnetic rocks show a common dependence of the residual magnetization on magnetic susceptibility. A regular deviation of the residual magnetization direction from that of the present magnetic field of the earth is observed. The mechanism of the thermomagnetization process is as follows: the magnetized body at every given moment is a certain cooling layer (the Curie layer) with the Curie temperature. In consequence of the lit-par-lit (gradual) cooling of the rocks their thermomagnetization in nature is necessarily dependent on the law of thin-layer magnetization. A mathematical analysis is given of the regularities observed in the direction of the residual magnetization vector in accordance with the cooling surface position (the Curie layer) with regard to the field of magnetization, the degree of magnetic susceptibility of rocks at the Curie temperature and the amount of residual magnetization itself. The authors suggest a general scheme of formation of thermoresidual rock magnetization. According to this scheme the different deviations of the residual magnetization vector actually observed may take place with a constant direction of the earth magnetic field. The tectonic-magmatic processes associated with the formation of geological units considered are interpreted in the light of the laws governing the direction of residual magnetization. --Authors' English summary.

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Many papers (Bersudsky, 1937; Grabovsky, 1953; Krutikhovskaya, 1956; Liogenky, 1954; Rogachev, 1951) on the magnetic properties of rocks have noted that besides their induced magnetization (I_i), rocks also have a residual magnetization (I_r). Moreover in the case of rocks containing ferromagnetic minerals, these quantities are of comparable magnitude, and for many igneous rocks $I_r >> I_i$. This general statement has also been fully confirmed by data obtained from a study of the magnetic properties of rocks of the Ukrainian shield.

Table 1 and Figs. 1 and 2 show the mean values of χ and the ratio of the magnitudes $I_r : I_i$ obtained for certain groups of the rocks that were investigated.

From Table 1 it is clear that in the case of basic and ultrabasic rocks of igneous origin, the residual magnetization as a rule is considerably greater than the induced magnetization. For this group of rocks, data on the relationship of I_r to χ are not available. As regards metamorphic rocks of both igneous (serpentinites) and sedimentary origin, these are characterized by a decrease in the ratio $I_r : I_i$ and an increase in the magnitude of χ (fig. 1).

Figure 2 shows curves of the change in the ratio $I_r : I_i$ and in I_r as functions of χ and I_i for the magnetite-bearing quartzites of the southern part of the Kremenchug magnetic anomaly. These curves were drawn from the mean values of χ and I_r at specific points along the change in χ. The number of specimens characterizing these intervals ranges from 2 to 23. In these curves one observes the same kind of change in the function $I_r : I_i = f(\chi)$.

From the curve of the function $I_r = f(I_i)$, it can be seen that as I_i increases the residual magnetization also increases, although more slowly. After I_i has reached a certain value (in this case about 0.1 CGS μ), I_r increases very slowly with the increase in I_i. To judge from the curves in Fig. 1, this rule is also typical of other rocks as well. The reason for this phenomenon has not been explained.

The fact that in regard to their magnitudes, the residual and induced magnetization do not follow the same rules (table 1 and figs. 1 and 2) has also repeatedly been noted by other researchers (Grabovsky, 1953; Kuzhelov, 1957; Liogenky, 1954). The considerable number of measurements available at the present time all show that the trends of the residual and induced magnetization are not, as a rule, the same, and in a number of cases move in

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[1] Translated from Obrazovaniye ostatochnogo namagnicheniya i yego raspredeleniye v gornykh porodakh: Sovetskaya geologiya, 1960, no. 2, p. 125-138.

[2] Ukrainian Geophysical Prospecting Section of the Institute of Geological Sciences of the Academy of Sciences of the U.S.S.R.

TABLE 1

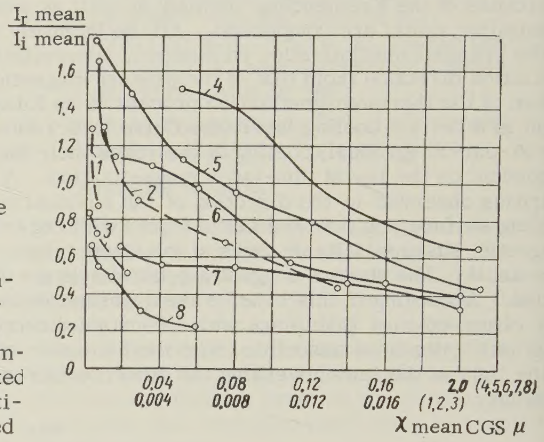
Rock	Number of samples	$X \cdot 10^6$ CGS μ	$\frac{I_r \text{ mean}}{I_i \text{ mean}}$
Gabbro-peridotite	77	8, 600	3. 3
Gabbro	980	6, 300	7. 6
Gabbro-olivine	366	4, 470	1. 34
Gabbro-norite	84	4, 150	0. 68
Gabbro-anorthosite	668	1, 510	1. 64
Labradorite, gabbro-labradorite	386	1, 200	1. 10

opposite directions (Bersudsky, 1937; Krutikhovskaya, 1956; Kuzhelov, 1957; Liogenky, 1954; Loguchev, 1951).

There are a number of theories to explain the origin of residual magnetization (Grabovsky, 1953; Loguchev, 1951). Without taking time to examine them, it will merely be said that the best founded at the present time is the theory of thermoremanence.

The problem of the distribution and the conditions of formation of of residual magnetization must evidently be solved not only through experimental researches, but also by a systematic study of the magnetic properties of oriented specimens. Investigations of residual magnetization in oriented specimens have been carried out by the authors of the present article, using rocks from the Volhynian gabbro-anorthosite massif (G. K. Kuzhelov) and magnetite quartzites of the Kremenchug magnetic anomaly (Z. A. Krutikhovskaya). The samples were taken from drill cores, and the specimens were oriented by the method proposed by G. K. Kuzhelov (1956).

A. A. Palkanov (1948) has attributed the origin of the gabbro-anorthosite Volhynian



1 - serpentinites (Pobuzh'ye), 2 - serpentinites (Nikopol'), 3 - hornblende-chlorite schists (Nikopol'), 4 - magnetite jaspilites (Kremenchug), 6 - amphibole-magnetite-cummingtonite schists (Kremenchug), 7 - magnetite hornstone (Krivoy Rog), 8 - amphibole-hornblende-magnetite schists (Krivoy rog).

FIGURE 1. Graphs showing the relationship between the ratio $I_r : I_i$

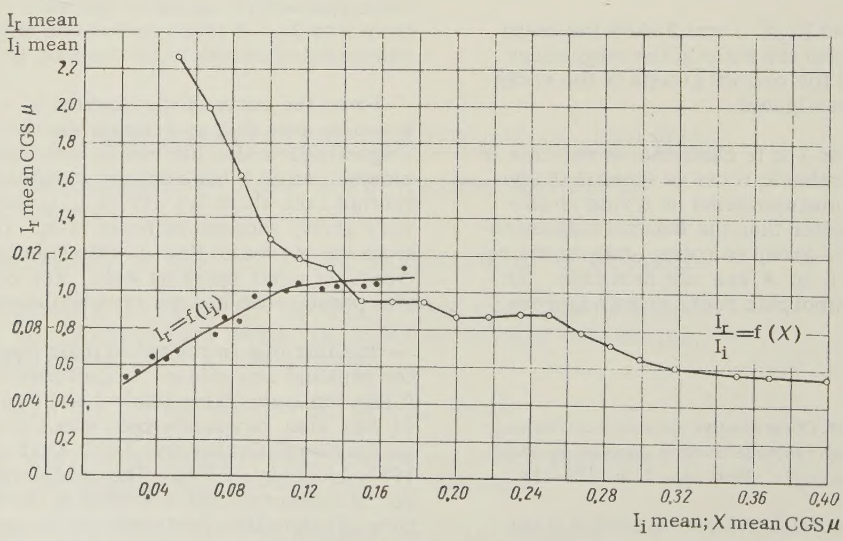
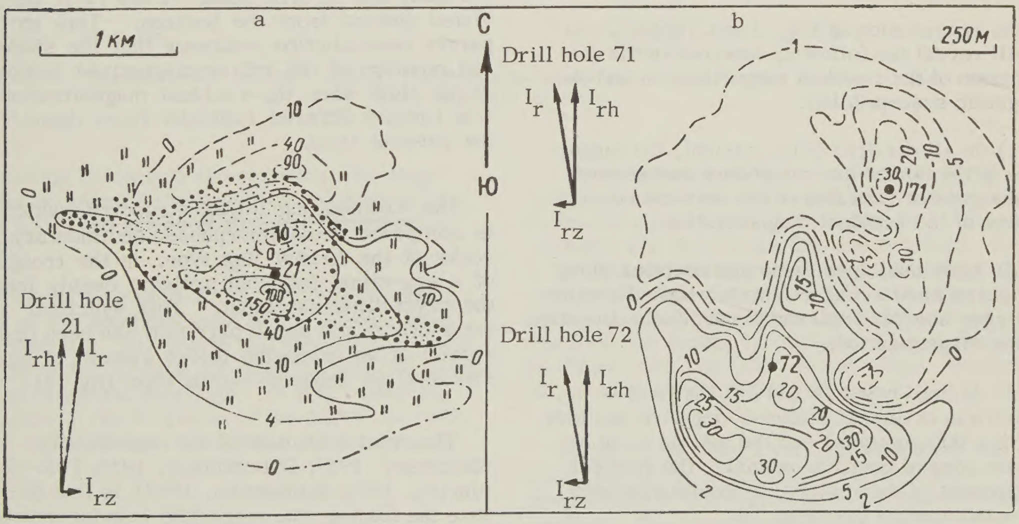


FIGURE 2. Graphs showing the relationship of I_r to I_i and of $I_r : I_i$ to X for quartzites of the southern end of the Kremenchug magnetic anomaly.

massif to tectonic faulting of the Precambrian basement in post-Proterozoic (?) times. This massif is part of an interformational pluton, intruded between the crystalline basement and the sedimentary series overlying it. The structure of the pluton includes silicic basic, and ultrabasic rocks. The basic and ultrabasic rocks are gabbro-anorthosites, gabbro-labradorites, gabbro-peridotites, olivine gabbro and gabbro-norites. The ferromagnetic minerals in these rocks are titanomagnetite and small quantities of magnetite and pyrrhotite. The greatest magnetization was found in the gabbro, gabbro-peridotite, gabbro-norite and olivine gabbro. These rocks, which are encountered together, contain all the local anomalies Z_a, which in individual cases reach 5-15 thousand gammas. Above the gabbro-anorthosites and gabbro-labradorites an intensified (to 100 - 200 gammas) "sporadic" magnetic field is observed.

Tables 1 and 2, and also Figure 3, show that the most important factor in the creation of the magnetic anomalies on the Volhynian massif is residual magnetization. A typical peculiarity of the magnetic field over the massif of basic rocks is the fact that, along with the local positive anomalies, there are adjacent negative anomalies of equal intensity, the latter always being located to the north, northwest or northeast of the former.

In order to study the distribution of the residual magnetization and to explain the causes of the negative anomalies, cores from five drill holes were investigated. Holes 11 and 12 were drilled vertically in an area where the anomaly is elongated in a nearly north-south direction. In length the anomaly can be traced for 3 km; its width at the 400-gamma isodynamic contour line is 350 m. The greatest value of Z_a is 1,000 gammas. These maximum anomalies correspond to the gabbros, which occur among the gabbro-anorthosites in a narrow band 350 m wide. Hole 21 was drilled in the region of the positive extreme (see fig. 3). In this drill hole, as well as a number of others, were found gabbros occurring among gabbro-anorthosites. Drill hole 71 was placed at the center of the area characterized by a negative anomaly Z_a of -3,000 gammas, and drill hole 72 in the area of a positive anomaly adjacent to the above-mentioned negative anomaly (see fig. 3). One drill hole penetrated 130 m and the other 150 m through gabbro-peridotites and gabbros, before exposing the gabbro-anorthosites. .Thus it was found that all three anomalies are determined by the gabbro-peridotites and gabbros occurring among the gabbro-anorthosites, and that the rocks encountered in the areas characterized by negative anomalies differ in no way, in their structure and composition, from the similar rocks of the area with the positive anomaly. These are the geologic circumstances under which the rocks under investigation occur.



- gabbro-peridotite
- gabbro-anorthosite
- isodynamic lines, in hundreds of gammas
- drill holes
- mean values of the residual magnetization vector (I_r) and of its vertical (I_{rz}) and horizontal (I_{rh}) components

FIGURE 3. Examples of magnetic anomalies, caused for the most part by residual magnetization

The present authors have determined the residual magnetization I_r and its components I_{rz} and I_{rh}, as well as the magnetic susceptibility X. The mean values of the total vector I_r for each of the drill holes are shown in Fig. 3, and Table 2 in addition shows the mean values of the induced magnetization vector and the ratio I_r mean: I_i mean.

TABLE 2

Drill hole number	$X \cdot 10^5$CGS μ				I_r mean / I_i mean
	I_{rz} mean	I_{rh} mean	I_r mean	I_i mean	
71	- 190	1, 220	1, 390	308	4. 5
72	- 210	1, 300	1, 470	340	4. 3
21	+620	4, 700	4, 900	510	9. 6
11	+ 21	99	139	112	1. 24
12	+ 37	100	124	133	0. 93

TABLE 3

Drill hole number	Number of specimens	$X \cdot 10^5$CGS μ			X_z mean / X_h mean
		X_{mean}	X_z mean	X_h mean	
71	46	715	570	860	0. 81
72	31	965	790	1, 140	0. 69
21	30	1, 030	1, 180	880	1. 34
11	51	300	260	310	0. 69
12	55	360	310	380	0. 81

Table 3 shows the mean values of the magnetic susceptibility (X) for each of the drill holes and its magnitudes along the vertical and horizontal axes, along with the relationships of these magnitudes.

An examination of Fig. 3 and Tables 2 and 3 will reveal the following features in the distribution of the residual magnetization and the magnetic susceptibility:

1) In all the drill holes studied, the magnitude of the horizontal component was several times greater than that of the vertical component of the residual magnetization.

2) Individual specimens and sections along the cores have a magnetization whose direction diverges sharply from the predominant direction of the magnetization.

3) In drill holes 71 and 72, the first of which was drilled in a zone of negative anomaly Z_a (-3, 000 gammas) and the second in an adjacent zone of positive anomaly, the vertical component of the residual magnetization was directed upward (see Fig. 3).

4) According to the data from four drill holes, the value of X in the horizontal direction is greater than in the vertical by 20 to 30 percent; only in the data from drill hole 21 does the reverse picture appear.

The shape of the magnetic anomalies, as well as the data from drilling, indicate that the magnetization of the geologic bodies was best facilitated in a direction close to that of the magnetization field -- that is, the magnetic field of the earth. Therefore the residual magnetization of the bodies under consideration, inasmuch as it is produced by the earth's field, should be in a direction close to that of the earth's magnetization field. Actually, as the investigation has shown (see fig. 3 and table 2), the residual magnetization in all the zones of anomalies that were studied has a direction closer to the horizontal than to the vertical, but in drill holes 71 and 72 it deviated upward from the horizon. This apparent contradiction indicates that the shape and position of the thermomagnetized bodies at the time when the residual magnetization was formed differed radically from those of the present time.

The Kremenchug folded structure, which is composed of metamorphosed sedimentary rocks of the Krivoy Rog type, is the trough of a syn-clinal fold that projects deeply into the crystalline basement. This synclinal structure is the small part that has been preserved of an extensive folded system of geosynclinal or subgeosynclinal type (fig. 4).

The opinion of most of the researchers (Belevtsev, 1955; Dobrokhotov, 1955; Polovinkina, 1954; Semenenko, 1953) is that before the folding, the magnetite-bearing quartzites that form part of the sedimentary-metamorphic series were a sedimentary formation containing amorphous iron and silicate compounds. In the folding process the iron compounds, under the action of the dynamic metamorphism and the thermal effect of the granitic magma, were altered into magnetite, evidently at a temperature higher than the Curie point.

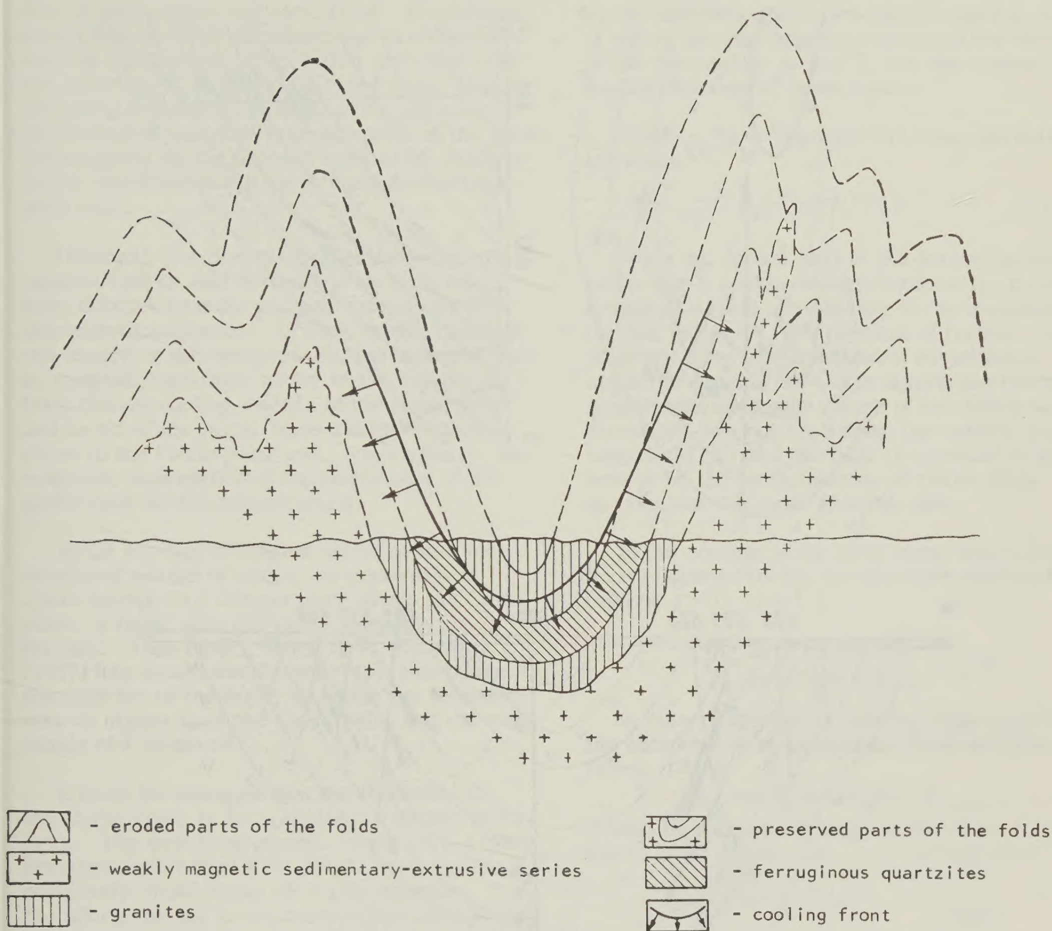


FIGURE 4. Hypothetical section through the Precambrian folded system in the region of the Kremenchug magnetic anomaly

In cooling below this temperature, the magnetite acquired a thermo-residual magnetization under the action of the earth's magnetic field.

The bedding map of the ferruginous quartzites of the southern nose of the Kremenchug syncline (fig. 5a) shows that the vertical plane of the vector I_r does not coincide with the plane of the magnetic meridian. In every case I_{rh} deviates in the direction of the dip of the beds, even in the areas where their strike is north-south.

The mean values (at definite intervals along the drill holes) of the projections of vectors I_r in the vertical plane perpendicular to the magnetic meridian are shown on the geologic cross sections (figs. 5c and d). If vector I_r had coincided with the direction of the earth's magnetic field, its projection in the plane of these sections would have been vertical.

The projection of I_r in the vertical plane oriented east-west deviates from the vertical in the direction in which the beds dip. The exceptions are drill holes 609 and 610 (figs. 5 a, c and d), where the projection of the vector I_r deviates to the east. This indicates that the holes have been drilled in the western flank of the fold; the trough is evidently east of the line of these holes, and the sections (figs. 5 c and d) are not accurately drawn.

Figure 5 b shows a vertical section in the direction of the magnetic meridian and the projections of the vector I_r in the plane of the section. The mean deviation of the vector's projection from the vertical is 45° in drill hole 609 and 57° in drill hole 610, whereas the magnetic field of the earth at this latitude deviates from the vertical by 25°.

Thus the direction of the residual magnetization of both igneous rocks and metamorphic rocks of sedimentary origin does not, in the

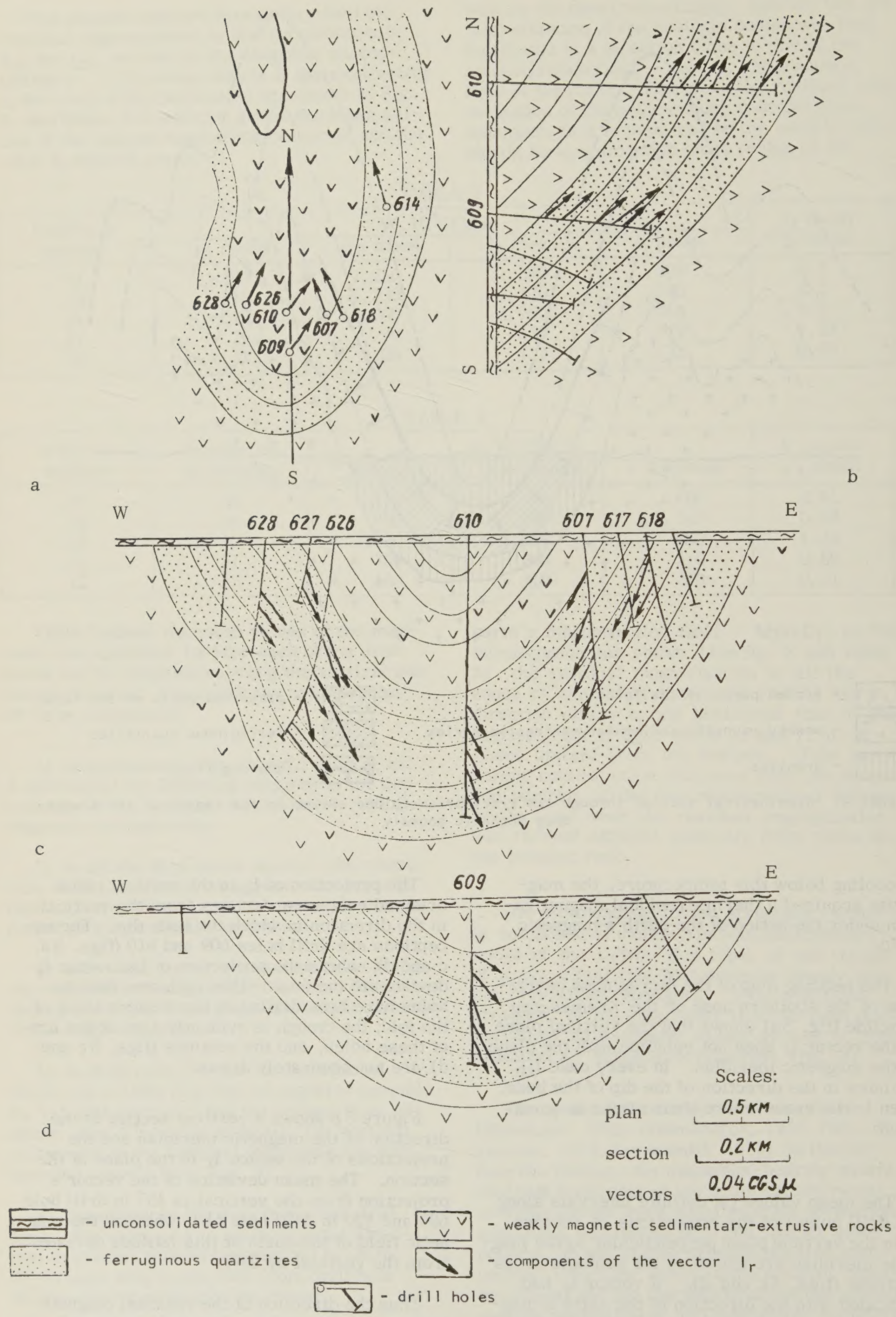


FIGURE 5. Results of a determination of the residual magnetization in the southern nose of the Kremenchug syncline

general case, coincide with the present direction of the earth's magnetic field. In addition, deviations in different directions are observed even in the case of rocks which are clearly of the same age. It should be noted here, that it is scarcely possible to explain the different directions of residual magnetization of the rocks investigated by the present authors by changes in the direction of the earth's magnetic field with time.

Obviously the distribution of the residual magnetization, and especially its direction, have depended on the specific conditions of thermomagnetization. In fact, on the basis of the theory of thermoremanence it is impossible to imagine conditions under which a geologic body that is cooling would, at the same time and in all of its parts, have a temperature close to the Curie point and, consequently, the magnetic susceptibility characteristic of the given rock at this temperature.

In the cooling of magma intruded into the overlying series of rocks, or generally of rocks heated to a temperature above the Curie point, a layer with the Curie temperature is formed. This layer, which G. K. Kuzhelov (1957) has called the Curie layer, surrounds the interior of the body, in which the temperature is higher than the Curie point and the magnitude of X is zero.

It must be assumed that the thickness of the Curie layer is very small in relation to its area. The overlying rocks, which have a temperature below the Curie point, have a comparatively small value of X; in essence, therefore, at any given moment the body being magnetized is the Curie layer. Since a bed-by-bed (gradual) cooling of the ferromagnetic body heated above the Curie temperature is inevitable, the thermomagnetization in every case follows the laws of magnetization of a thin layer. Hence the direction of the vector of thermoresidual magnetization at any point of a magnetically isotropic medium will depend on the position of the surface of the Curie layer relative to the direction of the magnetization field (in the case of rocks, this is the magnetic field of the earth), and on the magnitudes of the magnetic susceptibilities of the given rock at normal temperature and at the Curie temperature.

For a mathematical expression of this relationship, one may use the law of refraction of magnetic force lines when they cross the boundary between two media (Frish and Timoreva, 1953):

$$\operatorname{tg} \alpha_\theta = \frac{\mu_\theta}{\mu} \operatorname{tg} \alpha = \frac{1 + 4\pi \varkappa_\theta}{1 + 4\pi \varkappa} \operatorname{tg} \alpha, \qquad (1)$$

where: α and α_θ are the angles of deviation of the magnetic force lines from the line normal to the surfaces of the two media (see fig. 6 a); μ and μ_θ are the magnetic permeability of each of the two media; $\varkappa$ and $\varkappa_\theta$ are the magnetic susceptibilities of these media.

When $\varkappa_\theta \gg \varkappa$ Equation (1) takes the following form:

$$\operatorname{tg} \alpha_\theta \approx (1 + 4\pi \varkappa_\theta) \operatorname{tg} \alpha. \qquad (2)$$

When the cooled part of the ferromagnetic rocks has a residual magnetization I_r, creating a magnetic field comparable to the magnetic field of the earth, the process of further thermomagnetization is considerably complicated, since the successive Curie layers are thermomagnetized under the action of two fields whose directions are not the same: the earth's magnetic field (T) and the field of residual magnetization of the cooled series of rocks (H_r). Let us consider the most general case.

In the cooling of the first outer layer of the ferromagnetic rocks, for the first medium (where $\varkappa \approx 0$, $\mu \approx 1$)

$$\left.\begin{aligned} T_n &= T \operatorname{Cos} \alpha \\ T_t &= T \operatorname{Sin} \alpha \end{aligned}\right\}. \qquad (3)$$

In view of the known relationships between the components of induction (Frish and Timoreva, 1953):

$$B_{\theta_n} = T_n \text{ and } B_{\theta_t} = T_{t,\,\mu,\,\theta},$$

it may be considered that, in the case of the Curie layer (where $\varkappa = \varkappa_\theta$, $\mu = \mu_\theta$)

$$\begin{aligned} B_{\theta_n} &= T \operatorname{Cos} \alpha \\ B_{\theta_t} &= T_{\mu\theta} \operatorname{Sin} \alpha. \end{aligned} \qquad (3a)$$

After a certain layer of rocks has cooled below the Curie temperature, it acquires a magnetic permeability μ_1 and a residual magnetization, creating on the surface of the cooled series of rock an external magnetic field H_r, whose direction is at the angle α_θ to the plane normal to the cooling surface (fig. 6 b). The next Curie layer will be magnetized under the action of the magnetic induction B_1 created in the cooled part of the rock by the earth's magnetic field and by the external field H_r of residual magnetization of this series (fig. 6 c). In the medium with the magnetic permeability μ_1 (the cooled rock), the components of the induction will be expressed by the relationships:

for the vector B_1:

$$\left.\begin{aligned} B_{1n} &= T \operatorname{Cos} \alpha \\ B_{1t} &= T \mu_1 \operatorname{Sin} \alpha \end{aligned}\right\}; \qquad (4)$$

for the vector H_r:

$$\left.\begin{aligned} H_{rn} &= H_r \operatorname{Cos} \alpha_\theta \\ H_{rt} &= H_r \operatorname{Sin} \alpha_\theta \end{aligned}\right\}. \qquad (5)$$

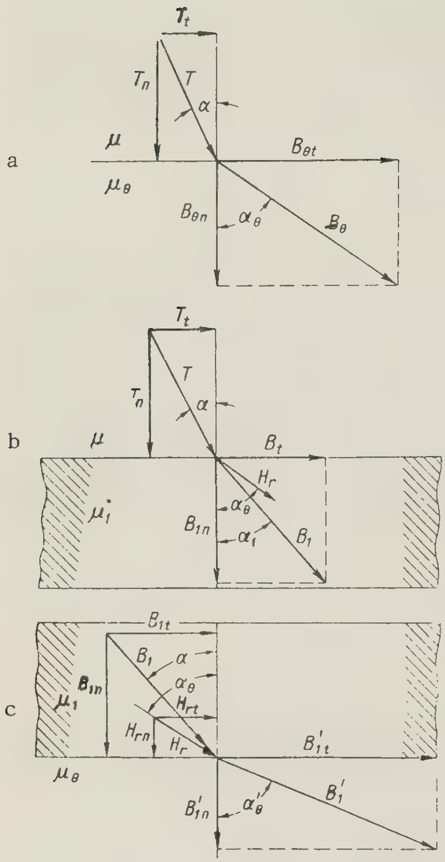


FIGURE 6. Diagram of the refraction of a magnetic field at the boundary of the Curie layer

In the next Curie layer, the magnetic induction B'_1 is created. From Equations (3), (3a), (4), and (5), the following components of the vector B'_1 are obtained:

$$\left.\begin{aligned} B'_{1n} &= H_r \operatorname{Cos}\alpha_\theta + T \operatorname{Sin}\alpha \\ B'_{1t} &= H_r \mu_\theta \operatorname{Sin}\alpha_\theta + T\mu_\theta \operatorname{Sin}\alpha \end{aligned}\right\} . \quad (6)$$

The angle of deviation α'_θ of the vector B'_1 from the plane normal to the cooling surface, with which the direction of thermoresidual magnetization in the next Curie layer (after its cooling) will coincide, is determined by the expression:

$$\operatorname{tg}\alpha'_\theta = \frac{\mu_\theta (T \operatorname{Sin}\alpha + H_r \operatorname{Sin}\alpha_\theta)}{T \operatorname{Cos}\alpha + H_r \operatorname{Cos}\alpha_\theta} . \quad (7)$$

Replacing α_θ by the angle α from Formula (2), Equation (7) may be rewritten as follows:

Since $\alpha'_\theta > \alpha_\theta$, in the next Curie layer the angle of refraction of the induction vector α''_θ increases still more -- that is, $\alpha''_\theta > \alpha'$, and so on.

In this manner, with the gradual cooling of the rock in each successive Curie layer the residual magnetization will deviate at a greater and greater angle from the plane normal to the cooling surface and, consequently, from the direction of the magnetization field T.

The components of the induction field T will have the same magnitude in all the Curie layers, since the relationship of μ_θ to μ_1 for a given rock is considered to be constant. As regards the field H_r, its direction gradually changes, and along with it the magnitudes of its components also change.

It may be assumed that after the cooling of a certain series of rocks, the magnitude of the vector H_r directly at its surface will subsequently show little change. Inasmuch as its direction changes in each layer, deviating farther and farther from the line normal to the surface of cooling, there will also be a change in the direction of the resulting effective magnetization field in each successive Curie layer. It is obvious that the ultimate deviation of the residual magnetization is characterized by the condition in which $\alpha_\theta \to 90°$. Then $\sin\alpha_\theta \to 1$ and $\cos\alpha_\theta \to 0$ and therefore $H_{rn} \approx 0$ and $H_{rt} \approx \mu_\theta H_r$. In this case, expression (7) takes the form:

$$\operatorname{tg}\alpha'_{max} = \frac{T \operatorname{Sin}\alpha + H_r}{T \operatorname{Cos}\alpha}\mu_\theta = \frac{T \operatorname{Sin}\alpha + H_r}{T \operatorname{Cos}\alpha}(1 + 4\pi\varkappa_\theta). \quad (9)$$

The equation thus obtained determines the limit of deviation of the direction of thermoresidual magnetization from the plane normal to the cooling surface. On the other hand, when $\alpha'_\theta \to 90°$ the right side of Equation (9) approaches infinity, but since the numerator of the fraction is a finite quantity (for angles $\alpha \angle 90°$), it is obvious that

$$H_r = T \operatorname{Cos}\alpha \sqrt{1 + \mu_\theta^2 \operatorname{tg}^2\alpha} = 0.$$

Whence:

$$\mu_\theta = \frac{\sqrt{H_r^2 - T^2 \operatorname{Cos}^2\alpha}}{T \operatorname{Sin}\alpha} . \quad (10)$$

This expression characterizes the condition under which there is the greatest deviation of the residual magnetization from the magnetization field.

$$\operatorname{tg}\alpha'_\theta = \frac{\mu_\theta\left(T \operatorname{Sin}\alpha \sqrt{1 + \mu_\theta^2 \operatorname{tg}^2\alpha}\right) + H_r \mu_\theta \operatorname{tg}\alpha}{H_r + T \operatorname{Cos}\alpha \sqrt{1 + \mu_\theta^2 \operatorname{tg}^2\alpha}} . \quad (8)$$

In Figs. 7 a, b, c, d are shown curves of the relationship between the angle α_θ' and the magnetic susceptibility $\varkappa_\theta$. Figure 7 a corresponds to the case in which the residual magnetization field is, for all practical purposes, very small in comparison to the earth's magnetic field. The curves in Figs. 7 b, c, d are drawn to show the effect of the residual magnetization field as measured on core samples from holes drilled in the Volhynian pluton. the thermoresidual magnetization vector from the direction of the magnetization field.

From Formula (9) and the graphs (see fig. 7), it is possible to estimate the order of magnitude of the magnetic susceptibility $\varkappa_\theta$ of the rocks b being investigated, at the Curie temperature θ.

We have considered the process of thermomagnetization of isotropic media. In the case

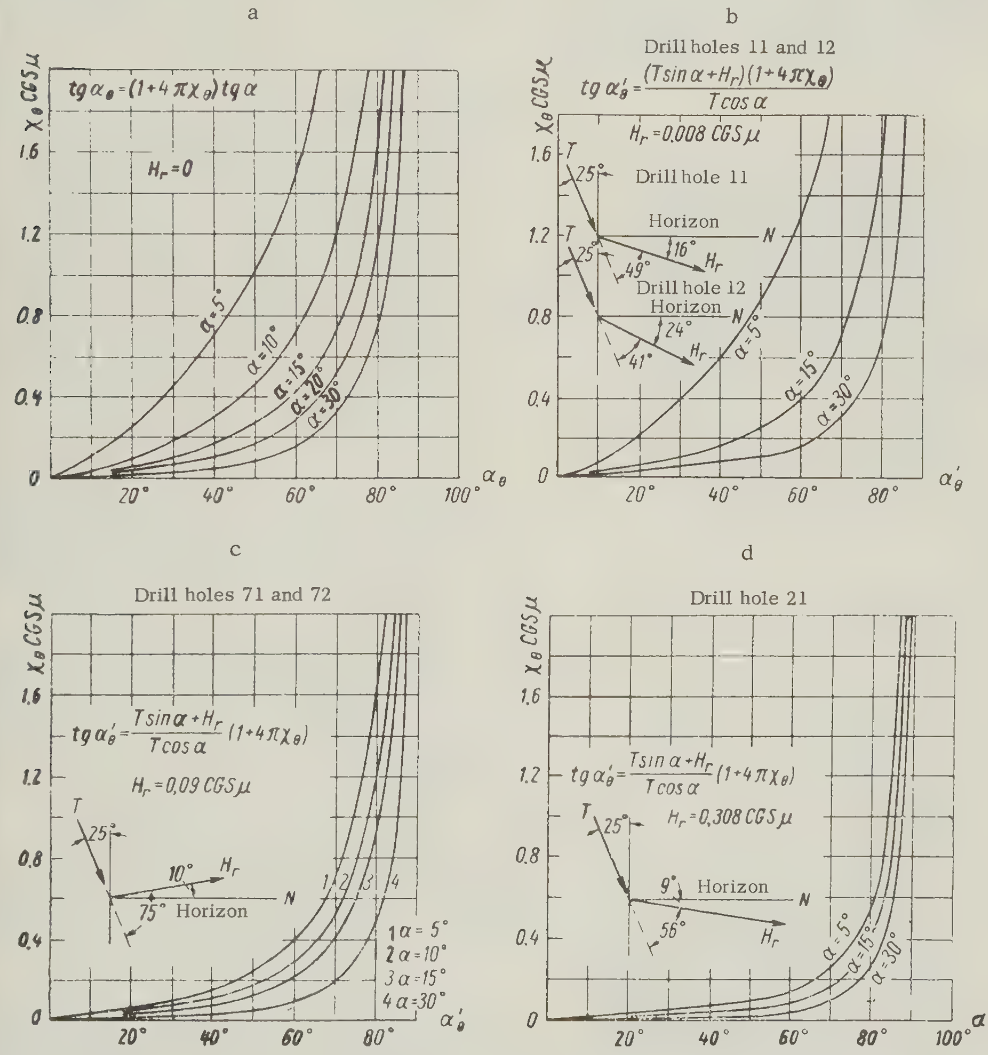
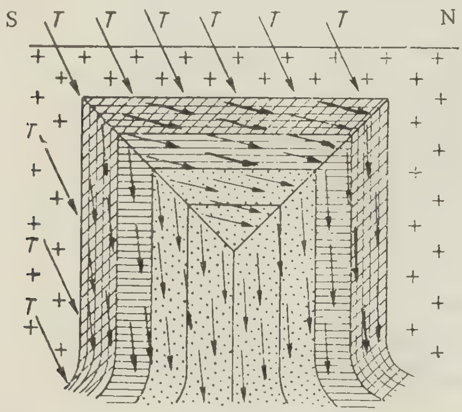


FIGURE 7. Curves showing the relationship between the direction of the residual magnetization vector and α, χ_θ and H_r.

A comparison of the curves for the different magnitudes of H_r shows how great is the effect of the residual magnetization field H_r on the thermomagnetization process of the rocks. After a certain layer of rocks has acquired a thermoresidual magnetization, in the succeeding layers there is a "spontaneous" deviation of of anistropic media, and particularly in the case of the Kremenchug ferruginous quartzites, in which the magnetite forms thin interlayerings with the quartz material, the components of the residual magnetization along the bedding planes must be greater than those determined by M. A. Grabovsky and S. Yu. Brodskaya

(1958). In these rocks, apparently, the present direction of the residual magnetization is the result of the total effect of both the thermomagnetization in each successive bed and the influence of the rock's anisotropy.

On the basis of the data obtained on the direction of the thermoresidual magnetization and of their interpretation from the standpoint of thermoremanence, the present authors have suggested a general scheme for the process of thermomagnetization of rocks. This process is illustrated in Fig. 8, in the form of an idealized diagram of the cooling of a geologic body heated to a temperature above the temperature θ .



- surrounding rocks
- shell of the intrusion cooling below the Curie Point
- Curie layer with temperature θ
- rocks with temperature θ
- region of primarily horizontal residual magnetization
- region of primarily vertical residual magnetization

T - magnetic field of the earth

FIGURE 8. Diagram of the formation of thermoresidual magnetization

The intrusion of magma into the overlying series of rocks is depicted as a round cylinder (which resembles a stock); for the sake of simplicity, it will be assumed that the body cools uniformly on all sides except the side next to the source of heat (the magma chamber). According to what was said above, the upper part of the body will acquire a residual magnetization whose direction is close to the horizontal, and its sides a magnetization whose direction is close to the vertical. In the upper part of the intrusion is a region of primarily horizontal magnetization in the form of a cone, whereas the remaining parts of the intrusion are magnetized in the direction close to the vertical, resulting in a figure shaped like a funnel.

The scheme described here differs essentially from that suggested by G. K. Kuzhelov (1957), which assumes a decrease in the residual magnetization toward the center of the body. Mathematical analysis of the phenomenon shows that in a single-phase intrusion of magma, such a decrease cannot occur. The surface of the cooling magma will have a very different shape and position relative to the magnetization field; the cooling will also take place gradually and unevenly. Accordingly the residual magnetization will also have very different directions and magnitudes.

The results of the investigation of I_r in Volynya and in the region of the Kremenchug anomaly suggest the following observations. In Volynya the anomalies Z_a are produced by the gabbros and gabbro-peridotites, which occur in the form of stocks, lenses and other bodies within weakly magnetic gabbro-anorthosites. In almost all known cases the anomalies Z_a are of a combined nature -- positive anomalies accompanied by negative anomalies of comparable magnitude, which are always located to the north of the fomer. The rocks exposed in the positive and negative anomaly areas do not differ from each other in composition, magnetic susceptibility or residual magnetization. Only a very small part of the observed anomalies can be attributed to induced magnetization.

In the meridional section the contacts of the magnetized rocks are approximately the same as the points of the extreme values of Z_a (see fig. 3). From all that has been said, it can be concluded that the observed anomalies are determined mainly by the field of residual magnetization. The results of the determination of I_r on the specimens and the nature of the magnetic field (see fig. 3) leave no room for doubt that the direction of the residual magnetization does not coincide with the direction of the earth's magnetic field. The direction of I_r is closer to the horizontal than to the vertical, but in certain cases (drill holes 71 and 72, see fig. 3) the vector I_r inclines upward from the horizontal by an angle of as much as 10^o. This direction of the thermomagnetization can exist, however, only if the surface of cooling (the Curie layer) is inclined toward the south at an angle of more than 10^o but less than 25^o.

Judging from the nature of the observed field (see fig. 3) and comparing it with the scheme of the formation of I_r (fig. 8), it appears that there are no parts of the body magnetized primarily in the vertical direction. This indicates that the gabbroic and gabbro-peridotite bodies cooled at the same time as the enclosing gabbro-anorthosites and gabbro-labradorites, so that the cooling from moved only upward.

From the distribution of the residual magnetization in the Kremenchug ferruginous quartzites, one may draw some conclusions about the time of their thermomagnetization and the con-

tions of their folding. The Kremenchug uartzites were initially horizontal sedimentary rmations. The residual magnetization was roduced either before or after the formation of e folds. In the first instance, the vector I_r ould be able to deviate from the direction of e magnetization field (of the earth) only in the ertical plane of the magnetic meridian, and ould have no azimuthal deviation. Then, after e folding of the rocks, the vector I_r, being rigidly fixed" to the beds, would also be roated together with the latter. The component I_r in the plane perpendicular to the magnetic eridian would at every given point be directed long the line normal to the lines of the bedding, ward the recumbent side of the beds. In eality, as may be seen from Figs. 5 a, b, d, e vector I_r has a regular azimuthal deviation the direction of the dip of the beds. Hence e conclusion follows inevitably that the rocks nder investigation have acquired their residual agnetization after being crumpled into folds. one agrees with the statement that the quartzes acquired their residual magnetization as a esult of thermomagnetization (at the temperaure θ), this layer must necessarily have been e Curie layer. The direction of the vector in different parts of the fold indicates that e cooling front (the surface of the Curie layer) ore or less corresponded to the surface of e bedding, as shown in Fig. 4. In the present ross section the fold is surrounded by granites; may therefore be conceived that the granitic agma in the process of folding was intruded nto the adjacent anticlinal parts of the folded ystem and thence heated up the synclinal fold.

After the termination of these tectonic and gneous processes, a gradual cooling of the agma and the rocks overlying it began. If e cooling front had moved only downward rom above, the vector I_r would evidently not how any clear and regular azimuthal deviaion.

CONCLUSIONS

The above-mentioned materials from inestigations by the present authors provide e basis for the following conclusions:

1) Thermoresidual magnetization of rocks ontaining ferromagnetic minerals is comarable in magnitude to the induced magnetiation, and in the case of basic and ultrabasic gneous rocks it is in a number of instances any times greater than the induced magnetiation.

2) In each rock taken individually, the ratio $_r$:I_i decreases with the increase in χ, tending oward a certain ultimate value for the given ock.

3) With the increase in χ, and consequently I_i, for the given rock, I_r increases also, but after χ has reached a certain value this increase is retarded and I_r tends to approach a definite limit.

4) Thermomagnetization of rocks resulting from their bed-by-bed (gradual) cooling inevitably follows the laws of magnetization of a thin layer.

5) At each given point in the geologic body, the direction of thermoresidual magnetization is determined by the position of the cooling surface (the Curie layer) relative to the magnetization field (angle α) and by the magnetic susceptibility χ_θ of the rock at the Curie temperature (θ).

6) In the case of rocks whose magnetic susceptibilities at the Curie temperature χ_θ considerably exceed their magnetic susceptibilities at normal temperature χ_1 (much less than θ), the direction of the thermoresidual magnetization should, in general, not be the same as the direction of the magnetization field (of the earth), either in azimuth or in the vertical plane. The directions of the thermoresidual magnetization and the magnetization field will be the same only in particular cases, when $\alpha = 0$, and when $\alpha = 90$.

7) The greater the magnitude of the residual magnetization, all other conditions being equal, the more its direction will deviate from that of the earth's magnetic field.

8) Without any change in the direction of the earth's magnetic field, rocks of the same age, and even from individual parts of the same geologic body, may have different directions of thermoresidual magnetization; on the other hand, rocks of different ages, under different directions of the earth's magnetic field, may be thermomagnetized in the same direction. For this reason the direction of the earth's magnetic field in different geologic epochs cannot, in general, be determined from the directions of the thermoresidual magnetization in rocks of different ages. This can be judged only when the positions of the cooling surfaces (the Curie layers) in space, the magnitudes of χ_θ and the relationships of T and H_r in these rocks are the same.

9) From the distribution of the thermoresidual magnetization and especially from its direction, one may judge the nature of certain tectonic and igneous processes taking place in the production of certain geologic formations, as well as certain elements of the present structure of thermomagnetized rocks (the limits of their distribution, the direction of their dips, etc.).

As shown by the results of magnetic surveys and of an investigation of the residual magnetization of rock samples, a lack of coincidence

of the directions of the thermomagnetization and the induced magnetization of basic and ultrabasic intrusive and extrusive rocks is frequently observed in Volynya, Transcarpathia, the Sea of Azov and the Middle Dnepr regions. It must be supposed that this phenomenon is universal.

Further study of thermoresidual magnetization must be based, along with mass determinations of the magnitude of the vector I_r and its direction, on rock specimens and on investigations of the X_θ and the coercive intensity of various rocks, their Curie temperatures and the effect of pressure on these constants. There is also a need to perfect the method of determining I_r in weakly magnetic rocks.

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SOME SPECIAL FEATURES OF THE FORMATION AND DISTRIBUTION OF MERCURY DEPOSITS[1]

by

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• translated by Paul T. Broneer, R & R Inc. •

ABSTRACT

This article briefly discusses the world distribution of mercury deposits. These are classified according to their associated minerals: mercury alone, mercury-antimony, mercury-arsenic, mercury-antimony-arsenic, mercury-lead-zinc and mercury-quartz-gold. The deposits are also categorized by the types of rocks in which they occur and by the geologic structures with which they are associated, i.e. (in beds at the crests of anticlinal structures, on the flanks of folds and at the intersections of ore-bearing strata with faults; in thrust sheets and linear zones of fracturing; as veins within tectonic ruptures; and in local structures of varying origin. The metallogenic ages of the ore occurrences are grouped in five categories: Alpine (Tertiary and Quaternary), Mesozoic, Hercynian, Caledonian and older, and undetermined. Some details are given on the times of mercury mineralization in the history of the folded areas, the emplacement of the deposits in particular parts of folded systems, and on the extent of the deposits and the quality of the ores in them.

-- P. T. Broneer

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The formation of mercury ore is widespread in the Soviet Union, but only Central Asia, the Donets Basin, the Gornyy Altay, Tuva and Transcarpathia contain deposits of industrial importance.

Individual deposits and occurrences of mercury ore have been found in the Caucasus, the Urals, Eastern Siberia and the Far East; but in these regions the deposits that have been discovered are represented either by small ore bodies with a low content of mercury or else by inadequately surveyed areas whose economic value has still not been determined.

The Dal'stroy, in its operations in recent years within the Koryak Range in the Kamchatka Oblast', has established the occurrence of mercury ores over a considerable area; an evaluation of the industrial importance of this ore region will be published in the next two or three years.

The operations of the Arktikrazvedka Trust (1946-1953) have established the widespread occurrence of cinnabar in ore slimes, as well as of zones of antimony-arsenic-mercury ore formation, in the western and central parts of the Taymyr Peninsula.

Beyond the borders of the U. S. S. R., considerable deposits of mercury ore are concentrated in the regions adjoining the Mediterranean Sea: Spain, Italy, Yugoslavia, part of Turkey, Algeria and Morocco. Another mercury ore province is the southeastern part of the Chinese People's Republic. Ore deposits are also known to occur in North and South America, in Canada, the United States, Mexico, Venezuela, Colombia, Peru and Chile. In addition, there are Hg deposits in the Union of South Africa, Czechoslovakia, Japan, Australia and New Zealand.

THE TYPES OF MERCURY DEPOSITS

The overwhelming majority of mercury deposits in the Soviet Union and the world in general are hydrothermal formations. Fine scattered deluvial-proluvial placer deposits of cinnabar have been worked on a very small scale in the United States.

The Mineral Composition of the Mercury Ores

Seventeen minerals of mercury are known to exist at the present time; among these, the chief ore mineral is the sulfide of mercury, cinnabar.

The majority of hydrothermal mercury deposits belong to a single formation of Hg-Sb-As ores, whose composition includes cinnabar (HgS), stibnite (Sb_2S_3), realgar (AsS) and orpiment (As_2S_3), encountered in various proportions both in the ores of the deposits as a whole and in those of their individual parts. For this

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[1]Translated from Nekotorye osobennosti obrazovaniya i razmeshcheniya rtutnykh mestorozhdenii: in, Zakonomernosti razmeshcheniya poleznykh iskopaymykh: I, Izd. Akademiya Nauk SSSR, Moscow, 1958, p. 289-301. Footnote to title in original, "The present article was prepared at the direction of the All-Union Geological Fund during preparation of a general survey of the geology and reserves of mercury deposits". Reviewed for IGR by J. W. Ambrose.

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reason it is difficult to classify mercury deposits solely by the mineral composition of the ores, as in the case of other metals. Nevertheless, although the division is extremely tentative, within this basic and unified ore formation of mercury deposits, according to the quantitative development of the ore-forming minerals mentioned above, one can distinguish the following groups of deposits: mercury, antimony-mercury, arsenic-mercury and antimony-arsenic-mercury. To this list one may add the sometimes encountered deposits of non-ferrous metals (lead, zinc or copper) with mercury and of gold ores with mercury.

The greatest part of the mercury is concentrated in deposits of the first monometallic type; the known reserves of Hg are in deposits of antimony-mercury, arsenic-mercury and antimony-arsenic-mercury ores, and only very small amounts of mercury occur in deposits of lead-zinc and quartz-gold ores.

Monometallic mercury ores are typical of most of the deposits. In the Soviet Union these include the ores of Nikitovka (where stibnite is also found, although rarely), most of the deposits of Central Asia (except the Khaydarkan, the Dzhizhikrut, Magian and certain parts of the Chauvay deposits), Transcarpathia, the Caucasus (the Akheyskoye, Talakhianskoye, Tsesskoye, Tibskoye, Kyshkytskoye, Khpekskoye and Shakhdagskoye deposits), Oyrotiya, the Tuvinian Autonomous Oblast' and Kamchatka. Among the ores outside the Soviet Union, those of the monometallic type are the greatest mercury deposits in the world at Almaden in Spain, those at Idria in Yugoslavia, at Pfalz in Germany, Mernik in Czechoslovakia, all the deposits of the United States and Canada, those of the Dalsez-Nabrez region in Mexico, the deposits of South America (in Venezuela, Colombia, Peru and Chile), at Kara-Burun in Turkey, the chief deposits of China, the deposits of Japan, Australia and New Zealand (Puhi-Puhi). The composition of the ores of this type of deposit is determined by the development of the main ore mineral, cinnabar, which is usually associated with carbonates and quartz (chalcedony and opal). Secondary associations include: pyrite, marcasite, arsenopyrite, stibnite, tetrahedrite, realgar, orpiment, siderite, barite, fluorite, etc. The presence of clay minerals -- dickite, montmorillonite, kaolinite, halloysite, hydromica, allophane, etc. -- is very typical. Moreover, in the Terlingua deposit (U.S.A.) primary oxychlorides of mercury and compounds of mercurammonite and hydromercury (terlinguaite, kleinite, mossite) have been encountered, and mercury selenides (onofrite and tiemannite) have been found in the Marysvale deposit (U.S.A.).

Antimony-mercury ores are known to exist in the deposits of Central Asia (Khaydarkan, Chauvay, Dzhizhikrut, Magian), in certain deposits of China, in Italy (San Martino), and at Zlata Banja in Czechoslovakia; in Mexico, where the composition of the ores in the Huitzuco deposit includes primary complexes of mercury and antimony sulfides, there is livingstonite ($HgSb_4S_7$). The ores of this type, besides cinnabar, contain noticeable amounts of stibnite, and in the Central Asian deposits there is also fluorite.

Arsenic-mercury ores occur in certain deposits of the Caucasus (Kodis-Dziri, Chichkhivani, Madnis-Tskhali), in the Krasnoyarsk district (Uboyninskoye), in Italy (Monte Amiata) and Czechoslovakia (Malakhovo). Here, in addition to cinnabar, there are considerable amounts of the arsenic sulfides, realgar and orpiment.

Antimony-arsenic-mercury ores are encountered more rarely: they are found in certain parts of the Khaydarkan and Chauvay deposits in Central Asia and in some deposits in China. It has been observed that the ore bodies of this composition frequently have a zoned structure. Stibnite occurs in the immediate vicinity of the tectonic ore-feeding channels, cinnabar is concentrated somewhat farther away in the wall rocks, and still farther, in the surrounding rocks, there is realgar and orpiment. This zonality is determined by the differing capabilities of these compounds of penetrating and diffusing from the ore-carrying channels into the surrounding rocks during the process of ore formation.

Lead-zinc and copper ores associated with mercury are known in regions in which polymetallic or copper and mercury deposits occur. In such cases, cinnabar often appears in the composition of the polymetallic and copper deposits. This is true of the Kugitang Range in Central Asia, the Talakhian district in the Caucasus, the Santandera deposit in Spain, Montepona in Italy, Broken Hill in Australia, Grobe Gang in Czechoslovakia and other places. The chief ore minerals in such ores are the various sulfides (pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, stibnite, etc.), tetrahedrite, and in particular areas, cinnabar.

Quartz-gold ores with mercury are encountered in the Urals (the Olen'ye-Travyanskoye deposit), in South Africa (the Murchison deposit) and in Australia (gold telluride veins with mercury); in Chile there are gold and chalcopyrite ores with mercury, and the Urals contain accumulations of cinnabar in the loose quartz and barite gangue of the oxide zones of pyrite deposits. Their composition includes chiefly quartz, pyrite, gold and a certain amount of cinnabar, and in Australia also tellurides, including the telluride of mercury, coloradoite (HgTe).

The distribution of the surveyed reserves

and extractions of mercury ore in the Soviet Union, by the types of deposits, as of the first day of January, 1956, is shown in Table 1 in percentages.

TABLE 1

Type of deposit	Net reserves of categories $B+C_1$ as of 1 January 1956	Production in 1955
Mercury	55	47
Antimony-mercury	45	53

The Rocks Containing Mercury Deposits

A necessary condition for the formation of hydrothermal mercury deposits is the occurrence of permeable rocks. The rocks in which mercury deposits are found are mainly rocks with primary porosity or else rocks that have undergone secondary tectonic fracturing. The most widespread variety, in which 75.5 percent of the world's mercury reserves occur, are sandstones; the place of second importance is occupied by thin-bedded, fractured limestones, which contain up to 23 percent of the world's reserves; and all the remaining types of rock contain only 1.5 percent of the world's mercury.

The most valuable deposits of concentrated mercury ores are formed when the permeable ore-bearing rocks are overlain by rocks impermeable to water -- shales, clays and other dense rocks.

The Geologic Structures of Mercury Deposits

Although the mineral composition of the enclosing rocks is comparatively uniform, the geologic structure of the mercury deposits is distinguished by much greater variety. In literally all the mercury deposits, ore-carrying channels and ore-bearing structures have been identified among the geologic features determining the structure of the deposit. The ore channels are always tectonic fractures of deep occurrence.

The ore-bearing structures are more varied; among them, according to the kind of tectonic deformation, one may distinguish the following types determining the structural and morphological aspect of the mercury ore bodies and their geologic position:

Bedding structures:

1) Ore bodies in the crests of anticlinal folds,

2) Bodies in the flanks of folds,

3) Bodies at the point where folds favorable to ore formation are intersected by fractures;

Thrust zones and linear zones of fracturing:

4) Bodies along thrust faults and zones of fracturing;

Single tectonic fractures:

5) Veins in tectonic fissures;

Local structures of various origins:

6) Ore pockets.

The bodies in the crests of anticlinal folds are saddle-shaped occurrences along the axes of anticlines that have been cut by fractures -- the ore-carrying channels. The disseminations and segregations of cinnabar and associated minerals are found in brecciated and hydrothermally altered sandstones or limestones, which made up the cores of the folds, and are overlain by shales or other relatively impermeable rocks. Deposits of this type are the Khaydarkan in Central Asia, the principal deposits of China, Huancavelica in Peru, the Chisos, Mariposa and other deposits in the United States.

Bodies in the flanks of folds are found more rarely than those in the crests. They consist of strata of ore-bearing rocks with disseminations and segregations of cinnabar and its associated minerals. Such bodies occur in the Dzhizhikrut, Magian and Ashat deposits in Central Asia, at Krasnaya Gorka in Kamchatka and elsewhere.

Bodies located where fissures intersect beds favorable to ore formation are close to the above two types in their geologic position. They differ in the fact that the ore formations within the ore-bearing beds are drawn out in the form of a narrow lens along the fissure, and die out away from it. The structures of the greatest deposits of Europe -- Almaden in Spain, Idria in Yugoslavia and Monte Amiata in Italy -- are close to this in type.

Bodies along thrusts and linear fractured zones are chains of ore bodies. According to their structures, they may be divided into four varieties: 1) deposits consisting of linked pocket-like ore occurrences, within the rocks of the autochthonous thrust block and beneath the surface of the thrust; these rocks are usually impermeable; 2) deposits whose ore pockets or short vein-like bodies are located in branching feather-like fissures extending along thrusts or other fractures; 3) deposits whose ore pockets and short layer ore bodies are associated with the points at which a fracture intersects strata of rocks favorable to ore deposition; 4) deposits consisting of a chain of ore pockets in the broken rocks of

linear zones of fracturing. Deposits of this group are the Chauvay in Central Asia, the Aktash, Chagan-Uzun and Kuray in Oyrotia, the deposits of the Tsessko-Mamison ore field in the Verkhnyaya Racha in the Caucasus, Pinchi Lake in Canada and others.

Ore veins, or tectonic fractures filled with mercury ore, are comparatively rare. Such are some of the ore bodies in the Ayat and Olen'ye-Travyanskoye deposits in the Urals, the Uboyninskoye deposits in the Krasnoyarsk district, the Transbaykal deposits, the Kurshurli deposit in Central Asia, certain bodies of the Huancavelica deposit in Peru, the Kotterbach deposit in Hungary, the Moschwellandenberg deposit in Germany and others.

Ore pockets are typically small, local, more-or-less isometric segregations of mercury ore. Deposits of this group are encountered quite often, but they are, as a rule, of small size; they are associated with local areas of fracturing in the ore-bearing rocks, solution zones, sharp angles in the bends and folds of beds, areas of sharply curved fractures, or at the intersections of fractures, or in rocks that are brittle or otherwise favorable to the emplacement of the ores. As an example of the ore bodies of this type one may cite the majority of the small deposits of Central Asia, the deposits of Transcarpathia, many deposits on the west coasts of both North and South America, and small mercury deposits in Italy, Mexico, Japan and elsewhere.

The particular varieties of the structural-morphological types of deposits characterized above may be combined into the following three subdivisions: 1) layers, 2) pockets and 3) veins. The category of layers includes those mercury deposits whose chief ore bodies belong to the first three structural types of mercury ore formations. It must be kept in mind that the concept of a layer deposit includes all the ore contained in the ore-bearing stratum. If one further wishes to distinguish within these the areas of rich ores, determined by the internal structure of the layer, part of these deposits will belong to the category of pockets, which also includes the deposits of the fourth and sixth structural types, whereas veins are the deposits of the fifth type.

The largest mercury ore deposits in the Soviet Union and the world in general are layer deposits. Deposits of the pocket type are second in importance, and veins are minor in quantity. The distribution of the Soviet Union's reserves of mercury according to the categories of their deposits is shown in Table 2 (in percentages).

Thus, in view of the basic features of mercury deposits their mineral composition and structural and morphological peculiarities, they may conveniently be grouped into certain general categories. According to the geologic structure and the morphology of the ore bodies, they may be divided into three groups: 1) layers, 2) pockets and 3) veins. Within each group, according to the mineral composition of the ores, the following types of deposits may be distinguished: 1) mercury, 2) antimony-mercury, 3) arsenic-mercury and 4) others (non-ferrous metals with mercury, gold with mercury, etc.).

TABLE 2

Type of deposit	Net reserves of categories $B + C_1$ as of 1 January 1956	Production in 1955
Layer	84	93
Pocket	12	7
Vein	4	--

GEOLOGIC CONDITIONS GOVERNING THE FORMATION OF MERCURY ORE DEPOSITS

The overwhelming majority of the world's deposits of mercury ore were formed in the terminal stages of the Alpine metallogenic period, whose features have thus determined the conditions of their formation.

The Geologic Ages of Mercury Deposits

The map of the distribution of the world's mercury deposits (fig. 1) clearly shows that the greatest number of deposits are associated with the Mesozoic and Cenozoic (mainly Tertiary) folded systems of the earth.

Deposits which are Alpine (Tertiary and Quaternary) in the time of their formation are all the mercury deposits of the Tertiary folded regions of the Pacific Ocean belt and the Eurasian zone. To the interior, Alpine part of the Pacific Ocean folded belt belong the deposits on the American coasts -- in Canada (about 30 deposits, including the largest of them at Pinchi Lake), in the United States (in Oregon, Nevada and California, where more than 400 small deposits are known), probably all or most of the 200 deposits and ore occurrences in Mexico, the deposits in Venezuela (San Jacinto and others), Colombia (Kindpo, etc.), Peru (Huancavelica, etc.), Chile (Ovalle, etc.), New Zealand (Puhi-Puhi), and beyond, on the Asiatic shore, in Japan (about 20 deposits on the islands of Hokkaido and Honshu) and Kamchatka (the Koryak zone). The following deposits are concentrated in the Alpine folded zone of Eurasia: those in Spain (Almaden, etc.), Portugal, Italy (Monte Amiata, etc.), Yugoslavia (Idria, etc.), Czechoslovakia, Hungary, Rumania, Morocco, Algeria and Turkey, and farther east, within the U. S. S. R., those in Transcarpathia, the Caucasus, the Kopet-Dag and Kugitang (in

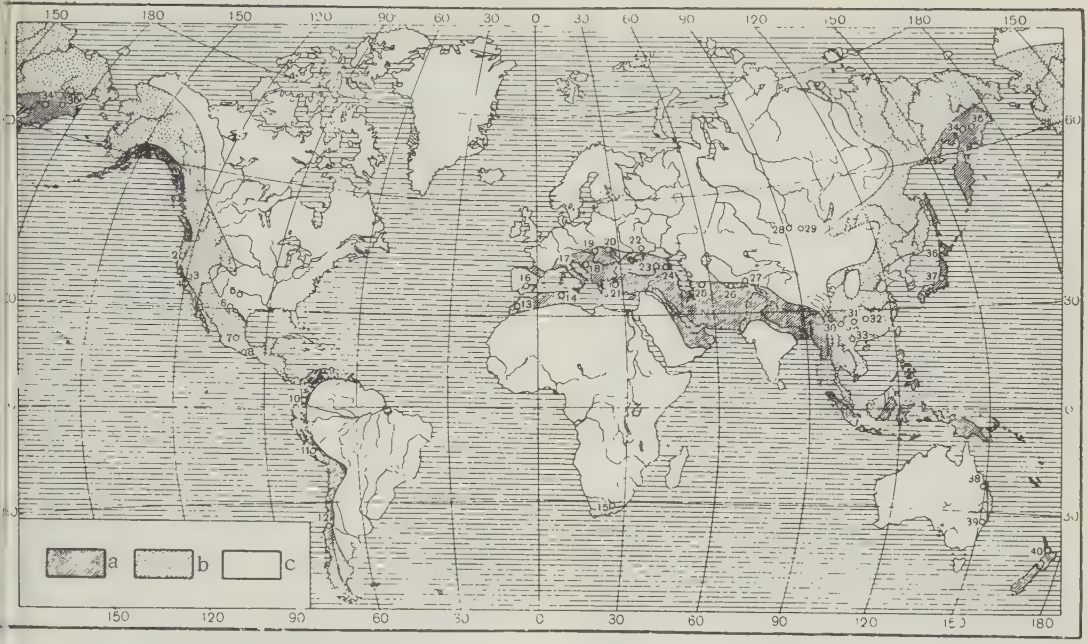

FIGURE 1. Mercury Deposits of the World

a - zones of Tertiary folding

b - zones of Mesozoic folding

c - zones of Hercynian and older folding

Mercury deposits

North America
1 - Pinchi Lake (Canada)
2 - Oregon; Opalie, etc. (U.S.A.)
3 - Nevada: Steamboat Springs, Pershing, etc. (U.S.A.)
4 - California: New Almaden, New Idria, etc. (U.S.A.)
5 - Texas: Terlingua, Marysvale, etc. (U.S.A.)
6 - Kansas: Peykie, etc. (U.S.A.)
7 - Dalsez, Nabrez (Mexico)
8 - Huitzuco (Mexico)
9 - San Jacinto (Venezuela)

South America
10 - Kindpo (Columbia)
11 - Huancavelica (Peru)
12 - Ovalle (Chile

Africa
13 - Ceuta (Morocco)
14 - Kos-el-Ma (Algeria)
15 - Murchison (Union of South Africa)

Eurasia
16 - Almaden (Spain)
17 - Monte Amiata (Italy)
18 - Idria (Yugoslavia)
19 - Czechoslovakia (Malakhovo, Mernik, etc.)
20 - Soviet Transcarpathia (Bol'shoy Shayan, etc.)
21 - Kara-Burn (Turkey)
22 - Nikitovka (Donbass, U.S.S.R.)
23,24- Caucasus: Naro-Mamison, Naro-Khpek, etc. (U.S.S.R.)
25 - Kopet-Dag-Karayel'chi, Kurshurli (U.S.S.R.)
26 - Kugitang (U.S.S.R.)
27 - Southern Fergana, Khaydarkan, Chauvay, etc. (U.S.S.R.)
28 - Oyrotiya-Aktash, Chagan-Uzun, etc. (U.S.S.R.)
29 - Tuvinian Autonomous Oblast' Terlingkhaya, etc. (U.S.S.R.)
30,31,32 - Southern China; Hunan, Kweichow, Kwangsi
33 - Tonkin (Vietnam)
34,35 - Koryakskoye in Kamchatka (U.S.S.R.)
36 - Itomuka (Japan)
37 - Yamata (Japan)

Australia-New Zealand
38 - Itokiwan (Australia)
39 - Pulganbir, Yulgilbar (Australia)
40 - Puhi-Puhi (New Zealand)

Central Asia).

Deposits of Mesozoic formation are primarily those of Southeastern China (in Hunan, Kweichow and Kwangsi provinces).

The deposits formed in the Hercynian metallogenic period are the small deposits of the Urals in the Soviet Union, probably those in Germany (the Pfalz ore district) and, possibly, those of Texas in the United States.

Caledonian and older deposits of mercury (accurately determined) are unknown.

Apart from the above, the time of formation of certain deposits is unknown or only tentatively established. The geologic age of the greatest

mercury deposits of the Soviet Union is still a controversial question. The Nikitovka deposits in the Donets Basin, for example, is represented by some investigators as being Late Paleozoic, and by others as Mesozoic or even Tertiary. In regard to the Southern Fergana deposits in Central Asia, which are located along the margin of the Alpine folded region, some students (V. I. Smirnov) posit an Alpine age, whereas others (N. M. Sinitsyn) consider them to be Hercynian. Different investigators have placed the time of formation of the mercury deposits of Oyrotiya and the Tuvinian Autonomous Oblast' within wide limits, from Caledonian or Mesozoic. V. A. Kuznetsov, who has studied these deposits in greatest detail, attributed their formation to the Mesozoic metallogenic period. The ages of the deposits in South Africa (the Murchison region) and Eastern Australia (Kilkiwan, Pulganban, etc.) are also unclear.

Nevertheless, even allowing for the undetermined time of formation of certain mercury deposits, there is full basis for stating that the great majority of the world's mercury is sharply concentrated in the latest stages of the geologic history of the earth's crust. This fact is also indicated by the approximate distribution of the world's reserves according to the chief metallogenic epochs (table 3).

TABLE 3

Metallogenic period	Amount of mercury (percent of world reserves)
Alpine	81.5
Mesozoic	10.0
Hercynian	0.5
Caledonian and older	0.0
Undetermined	8.0

The Position of Mercury Ore Formation in the History of Folded Regions

It is generally known that the development of folded systems of any age falls into three main stages: a geosynclinal stage, a stage of folding, and a post-folding stage that forms the transition to the platform stage.

In the early, or geosynclinal stage, characterized by the accumulation of thick sedimentary series, intensive volcanic activity and the intrusion of basic and ultrabasic igneous rock, there is no formation of mercury deposits. Yu. A. Bilibin's opinion that some mercury deposits are formed at the very end of this stage must be considered as unfounded.

In the middle stage, with its chief phases of folding and intrusion of batholiths of granitic magma, mercury deposits are also not formed. All the mercury deposits are created in the terminal stage of development of the mobile zones of the crust, as they are transformed into platform areas, and even in some cases as late as the platform stage of their geologic history. This last stage is typified by the ending of the geosynclinal regime even in the interior deeps of the geosynclinal system, the termination of folded deformation, an increase in dislocation by fracturing and faulting, and the occurrence of minor intrusions with a gradual cessation of intrusive activity in general. Since the mercury deposits are formed in the final period of this last stage of development of the mobile zones of the earth's crust, in post-intrusive times, they will be associated not with any particular intrusives, but with post-intrusive formation.

REGIONAL GEOLOGIC PECULIARITIES IN THE DISPOSITION OF MERCURY DEPOSITS

Mercury deposits are formed in particular types of folded systems and occupy definite positions within them.

The Connection between Mercury Deposits and Particular Folded Systems

Among the various folded (or geosynclinal) zones of the earth, there are three basic types.[4]

The first type includes folded regions in which there is a predominance of geologic formations of the early and middle stages in the development of the geosyncline, characterized by extensive ultrabasic and basic intrusives as well as batholithic masses of granitic rocks. An example is the folded zone of the Urals. Since mercury deposits are formed in the terminal period of the last stage of geosynclinal development, in folded regions of this type they will be encountered only rarely and be represented by small deposits.

The second type includes folded regions with a predominance of geologic formations of the middle stage of development of the geosyncline, in which there are widespread batholithic intrusions of granitic rocks, and the formations of the earlier and later stages are less extensive. A typical example is the Mesozoic folding on the Pacific coast of Eurasia. In such folded regions mercury deposits are more frequently encountered and in places reach considerable size.

Folded regions of the third type are those

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[4]This statement cannot be considered true to the fundamental types of geosynclinal zones of the earth. Here it applies only to the relative distribution of complexes of one age or another within the geosynclinal zones.-- Russian Editior.

in which the geologic formations of the early and middle stages appear in embryonic form and the processes characterizing the later stage have occurred more extensively. This type includes the Alpine zone of Eurasia and the interior part of the Pacific folded belt, with which, as noted above, the greatest majority of the world's mercury deposits are associated.

The Localization of Mercury Deposits within Folded Systems

Since they are formed in the terminal phases of the later stages in the transformation of geosynclines into folded systems, the mercury deposits are located in those parts of the system in which the processes of the later stages are localized. These areas, it is known, are the outer zones of the geosynclinal systems. It is with these that the major part of the mercury deposits are associated. Within the outer areas of the folded system, the mercury deposits are localized along the boundaries between local uplifts and depressions, which in these cases are as a rule divided by deep faults. Being emplaced along such boundary faults, the deposits usually form distinct ore zones. Even when the mercury deposits are formed in the post-folding, or platform period, they are determined by the large faults which are still active at the time of the mercury ore formation (as in the Donets Basin, Oyrotiya, the Tuvinian Autonomous Oblast', possibly in the Southern Fergana in Central Asia and elsewhere).

In all the ore provinces of the Soviet Union, the mercury deposits are distributed in belts whose positions are usually controlled by large faults or fault zones. In Central Asia, where the mercury and paragenetic antimony deposits are associated with the southern arcs of the Tien Shan, they form a distinct zone 450 km -- and, with its assumed flanks, 750 mm -- in length. In the Donets Basin the deposits of the Nikitovka ore field are stretched out in a chain 15 km long that follows the great "Sekushchiy" ("Intersecting") fault.

In Oyrotiya all the mercury deposits are associated with the enormous Kurayskiy fault, which marks the boundary between a region of upwarping and a region of subsidence and form a chain 450 km long.

In the Caucasus the mercury deposits form two clear zones, a northern and a central. Although the position of the first of these is not entirely clear, that of the second or chief zone is quite specifically controlled by a distinct thrust zone extending for hundreds of kilometers.

The mercury deposits in Kamchatka are connected with the Koryak zone, about 1,000 km long and 150 to 200 km wide, running from the Bay of Doubt in the north to the Tigil' River in the south. Within this elongated belt there are separate ore zones en echelon, of which the Enichayveyemskaya zone, which has been most thoroughly studied, is about 100 km long and 12 km wide.

In the central part of the Taymyr Peninsula the mineralization is associated with a fault zone trending northwest, which is 2.0 to 2.5 km wide and can be traced for 400 km (its assumed length is 1,500 km).

The disposition of the mercury deposits of Transcarpathia is less clearly determined tectonically, although here, too, they form two belts along the Vygorlat-Gutinskiy Range and the anticlinorium of the main Carpathian Range.

Outside the Soviet Union the regional geologic peculiarities of the distribution of the mercury deposits have been very little studied. But in the places where they have been investigated, the same picture emerges. In British Columbia (Canada), for instance, in the Pinchi Lake region, scores of mercury deposits are associated with a narrow zone of normal faulting which can be traced for several hundred kilometers.

THE QUALITY OF THE ORES AND THE SIZE OF THE MERCURY DEPOSITS

The quality of the ores is defined by their content of mercury: very rich ores are those with a mercury content of more than 1 percent, rich ores have 0.3 percent to 1.0 percent of mercury, medium ores contain 0.1 percent to 0.3 percent and poor ores less than 0.1 percent.

The vast majority of the world's mercury deposits, including those of the Soviet Union are small and medium in size. Large and very large deposits are rare. In the Soviet Union, the magnitude of the deposit is defined by the amount of surveyed net reserves, as the sum of all the categories ($A + B + C_1 + C_2$). On this basis, the group of very large deposits includes those with net reserves of more than 10,000 metric tons of mercury; large deposits are those from 1,000 to 10,000 metric tons, medium deposits contain from 200 to 1,000 metric tons and small deposits less than 200 metric tons.

The mercury ores are treated to obtain mercury metal by a simple procedure of direct metallurgical reduction, or a combined process of preliminary ore beneficiation followed by reduction of the resulting enriched ore concentrates.

Complex mercury-arsenic ores are usually treated by a process of metallurgical reduction in which the slightly crushed ore is oxidized by firing at 700° - 800° C. Complex antimony-mercury ores are usually treated by a combined

process involving mechanical beneficiation of the ore or firing in a vacuum. Usually 85 - 95 percent of the mercury is extracted from the ore. Mercury ore-refining plants are very compact and small in bulk, do not require great areas for their construction, and operate without any considerable expenditure of fuel and electrical energy.

THE WORLD'S MERCURY AS A RAW MATERIAL

Mercury has been known to mankind since antiquity. Some 3, 500 years ago it was widely used in China for the diffusion of gold and as a medicinal substance; from about 300 B. C. the Greeks and later the Romans were working the great deposit at Almaden (Spain).

Within the present area of the Soviet Union, ancient workings of mercury have been found in Central Asia. In pre-Revolution Russia only the Nikitovka deposit in the Donets Basin was exploited (from 1885 on); in the Soviet period the extraction of mercury ore has begun in Central Asia and in Siberia as well. Extensive geologic prospecting for mercury carried out during the Soviet regime has greatly expanded the amount of mercury available to industry as a raw material.

In their estimated reserves of mercury, the most important countries of the world are Spain and the Chinese People's Republic, whereas Italy, Spain and the Soviet Union lead in the amounts of mercury extracted.

No such survey of the amount of mercury available as raw material is available either for the other peoples' democracies or for the capitalist countries. A brief review of the characteristics of the world's mercury regions, according to the information at the disposal of the All-Union Geological Fund, is given below.

In the Chinese People's Republic the majority of mercury deposits are located within a well-known mercury zone at the border between Hunan and Kweichow provinces. This zone runs along the edge of a great uplift composed of Sinian and pre-Sinian (Late Proterozoic) rocks, where it adjoins an equally great downwarped region to the southeast. The mercury deposits are, for the most part, contained in carbonate rocks of the Cambrian system; more rarely, they occur in deposits of the Ordovician, Carboniferous, Permian, and Triassic. Their formation is connected with the Yangshan (pre-Late Cretaceous) metallogenic period. The surrounding rocks of most of the deposits are limestones, frequently dolomitized, and usually overlain by shales. According to the shapes of the ore bodies and the geologic structure, there are two groups of deposits: horizontal layer deposits and steeply dipping intersecting ore zones. The first group includes the deposits of the Vanshan and Lula districts, where the mercury mineralization occurs mainly in dolomitized limestones of the Cm_2^5 stage overlain by shales of the Cm_2^6 stage. These rocks have been gently folded and cut through by faults. The ore bodies, in the form of segregations, veinlets and disseminations of cinnabar and other minerals, are scattered throughout the stratum of dolomitized limestones below the shales, primarily in anticlinal folds but by faults. The individual ore bodies are small, only about 10 to 50 m in length and 0. 5 to 2 or 3 m in thickness, but the overall dimensions of the deposits are considerable. The second type of steeply dipping fractured zones in limestones with pockets of mercury ore, includes the deposits of the Tantszay district.

In regard to the mineral composition of their ores, the deposits of both groups have cinnabar as the chief ore mineral, but also include associated minerals: metacinnabarite, realgar, orpiment, stibnite, pyrite and galena, as well as calcite spreading out from the ore veins.

The average content of mercury in the ores (the lower extreme being 0. 06 percent) is about 0. 08 - 0. 12 percent; after grading in the course of extraction, a commercial ore containing from 0. 5 percent to 2 percent of mercury is obtained.

Although the mercury deposits in China have been worked since ancient times, the production of mercury at the present time is carried out exclusively by local organizations, and the active mines are not supported by reliably surveyed reserves. Throughout all the time that the Chinese deposits have been exploited, only about 5, 000 metric tons of mercury have been produced from their ores, an amount which clearly does not correspond to the enormous potential reserves of these deposits.

A few medium and a large number of small deposits of mercury ore are known in other peoples' democracies, such as Rumania, Hungary and Czechoslovakia.

In Spain is the vast deposit of rich mercury at Almaden, on the northern slopes of the Sierra Morena Range, about 200 km southwest of Madrid. This deposit has been worked since ancient times; systematic data on its exploitation have existed since 1499. During the many centuries that the Almaden mines have been worked, an enormous quantity -- some 800, 000 metric tons -- of mercury has been taken out. At the end of World War II the reserves of this deposit were estimated to be 250, 000 metric tons of 6 percent ore. The deposit has been exposed to a depth of 400 m, where some increase in the thickness of the ore bodies and in the content of mercury has been observed.

The ore mineralization is localized in three contiguous steeply dipping strata of quartz sand-

stones of the Lower Silurian. The industrially valuable ore can be traced along the strike for 250 m and has a thickness of 10 to 14 m and 7 to 12 m; its mercury content is 8 - 10 percent and in places as high as 15 - 20 percent. The chief ore mineral is cinnabar, which generally fills cavities, fissures and the interstices between the grains of quartz. The accessory mineral is pyrite. The richness of the ore and the vast reserves of this deposit are the reasons why the remaining numerous mercury deposits of Spain have been little prospected or exploited.

In Italy the chief mercury district is in the province of Tuscany, some 120 km north of Rome; here the greater part of the deposits are located on the eastern slopes of Monte Amiata, within a zone more than 32 km long and about 8 km wide. Approximately 120,000 metric tons of mercury have been extracted during all the time these deposits have been worked. The surveyed reserves of this province are reckoned at more than 20,000 metric tons of mercury. The mercury deposits are located both in a zone of faults along the contact between limestones of the Cretaceous and Upper Liassic and the overlying and underlying shales, and also under a cover of trachyte. The average content of mercury in the ore is 1.5 percent to 1.8 percent. The presence of realgar, orpiment, sulfur, stibnite and fluorite has been observed in the ores of certain deposits.

In the United States of America a considerable proportion of the mercury deposits is located in the states of Oregon, California, Nevada and Texas, within the Pacific Ocean ore belt, and associated with the late Mesozoic and Cenozoic cycle of ore formation. About 100,000 metric tons of mercury have been removed during the time the United States' mercury deposits have been worked.

In California up to 300 deposits are known, the greater part of which occur in Mesozoic sedimentary rocks, in a zone of fracturing along the contacts of ultrabasic serpentinized intrusives, associated with dikes of rhyolite and other extrusive rocks.

The largest deposit not only in California, but in all of America, is the New Almaden deposit, which was exploited from 1924 to 1926 (35,500 metric tons of mercury being extracted). The deposit was worked to a depth of 600 m. The ore bodies consist of breccia cemented by quartz, chalcedony, opal, calcite and dolomite. The ore minerals are cinnabar and pyrite; the mercury content was 1 percent and in places as high as 10 percent.

Oregon the majority of deposits are of the so-called "opalite type", consisting of zones of silicification in tuffaceous and other highly permeable sedimentary rocks (sandstones, unconsolidated conglomerates, etc.), and usually have the form of layer ore bodies whose location is contolled by steep normal faults. This type is exemplified by the state's largest deposit at Opalite, whose ore body (45,000 m^2 in area and no more than 15 m in thickness) is an occurrence of opalized tuffs with unevenly scattered cinnabar and terlinguaite ($HgCl \cdot HgO$).

In Canada, in the northern extension of the United States Cordillera ore belt in British Columbia, a number of mercury deposits are known, which from 1936 to 1942 yielded 768 metric tons of mercury. The largest deposit in Canada, at Pinchi Lake, was discovered in 1937.

Mexico is known to contain more than 200 mercury deposits, mainly in the eastern regions, in the state of San Luis Potosi. The largest is the Huitzuco deposit (in the state of Guerero), consisting of complex antimony-mercury ores from which, during 1869 to 1943, about 2,500 metric tons of mercury and 738 metric tons of antimony were extracted. About 9,000 metric tons of mercury have been removed from all the deposits of Mexico during the whole time they have been worked.

In Peru the largest deposit, both of the country and of South America as a whole, is the one at Huancavelica, which from 1570 to 1908 produced 51,362 metric tons of mercury with a metal content up to 5 percent. The deposit has been worked to a depth of 450 m. The remaining reserves contain only 0.1 - 0.2 percent of mercury.

Yugoslavia contains the great mercury deposit at Idria, which has been worked continuously for 450 years, and a number of small deposits. The ore mineralization at Idria is connected with brecciated dolomites, shell limestone and carbonaceous shales of the Paleozoic, in a zone in which these rocks have been thrust over Cretaceous limestones. The ratio of rich ores (containing 6 - 7 percent of mercury) to poor ores (containing 0.2 - 2.0 percent) is 1:30.

In Germany the mercury deposits of the Pfalz ore district, between the Saar and Rhine Rivers, were worked in the 16th and 17th centuries. This district consists of 8 ore fields forming a zone 50 km long and 10 - 15 km wide. The largest is the Lemberg deposit, whose ore is localized in a zone of intensively fractured and considerably altered porphyrites.

Two antimony-mercury provinces have been found in Africa: a northern (Tunisia-Algeria-Morocco) and a southern (the Murchison Range in the northeast of the Transvaal). The largest mercury deposit (the Kos-el-Ma) is in Algeria, 35 km from Batna.

In Australia mercury deposits are widely

known in the eastern part of the continent; the greatest are the Pulganbir and Yulgilbar deposits.

In New Zealand, 170 km north of Auckland, lies the Puhi-Puhi ore district, whose deposits have a mercury content up to 5 percent.

In Japan in 1945 about 20 deposits of mercury were being worked on the islands of Hokkaido and Honshu.

In addition to the above, individual mercury deposits are known in Venezuela, Colombia, Chile, Portugal, Greece, Turkey and other countries.

GEOLOGIC CONDITIONS OF EARTHQUAKE OCCURRENCES[1]

by

B. A. Petrushevskiy[2]

• translated by Paul T. Broneer, R & R Inc. •

ABSTRACT

Earthquakes with foci in the crust originate in the course geotectonic movements as a result of faulting. In many cases (probably in most of them) fault zones do not extend to the surface and, therefore, cannot be directly connected or compared with surface faults. If the immediate causes of earthquakes are always faults (such is the standpoint of the majority of scientists now), the geological causes, or in other words, geological conditions of earthquake occurrence are complicated and diverse; hence tectonic movements causing earthquakes take place in different geological environments with different histories of geological development. Seismic and geological investigations of the territory of the U. S. S. R. having been conducted recently by the Institute of the Earth's Physics of the Academy of Sciences of the U. S. S. R. permit us to assume that differences of the previous geological history (first of all, differences in the history of formation of major geological structures) leave their imprint on the differences of seismicity and peculiarities of the geological attitude.

The above relations are somewhat different in different regions of the western part of the U.S.S.R. There are distinguished: a) zones of Alpine folding; b) zones of young platforms (with a Paleozoic folded basement); c) zones of platforms which underwent rejuvenation in the Neogene-Quaternary epoch (irrespective of the age of folding of their basement).

The analysis of data obtained by seismic investigations using highly sensitive regional seismic stations indicates that these differences can be due to different depth of processes causing earthquakes. Judging from the depths of weak earthquake foci determined by regional stations one can assume that in the Alpine folding zone tectonic processes causing earthquakes primarily develop in the sedimentary layers of the crust and in its granite layer whereas in zones of the rejuvenated platforms the processes occurring in a basalt layer are of principal significance for seismicity. It is possible that this fact is connected with a more frequent occurrence of very strong earthquakes in the zones of rejuvenated platforms than in the Alpine folded zone as it is seen from the seismostatic materials on Eurasia (excluding the Pacific Asia). --Author's English summary.

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It is generally accepted at the present time that earthquakes whose foci are within the earth's crust occur as a result of faulting, which takes place at depths down to several tens of kilometers. Geologic investigations have fairly well established the fact that in many cases, the zones with which faults of seismic origin are connected do not extend all the way to the earth's surface and therefore cannot be directly associated with or compared to surface faults. It must be admitted that in the vicinities of the epicenters of a number of strong earthquakes, no large faults have been observed on the surface with whose movement these earthquakes might be connected (such as the Krasnovodsk earthquake of 1895, the Andizhan earthquake of 1902 and the Ashkhabad quake of 1948, and others).

Convincing data on the lack of correspondence between faults forming on the surface and folds being formed at a certain depth were obtained (Gzovskiy, 1954) as a result of an experiment in modeling folded structures performed in the Institute of the Earth's Physics of the Academy of Sciences of the U.S.S.R.

Thus the question of the direct cause of earthquakes can, in the opinion of most scientists, have only one answer. In one of his papers, M. V. Gzovskiy (1957) expresses the view that, inasmuch as earthquakes are associated only with faults of the slip-fault type, their physical cause must be seen in the tangential stresses in the earth's crust and the subcrustal parts of the earth. The regions with the greatest tangential stresses must also have the greatest seismicity. On the other hand, a more significant factor is the rate of plastic deformation of the earth's crust, which may be judged by the velocity gradients of its vertical movements.

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[1] Translated from Geologicheskiye usloviya vozniknoveniya zemletryasenii: Sovetskaya geologiya, 1960, no. 2. Russian footnote to title reads, "Paper read by author at the XXI International Geological Congress and recommended for publication by the National Committee of Geologists of the Soviet Union," however no record of this is evident from the Program, Volume of Abstracts, or Parts I-XXII of the published reports of the congress. Reviewed for IGR by J.W. Clarke.

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The greater these gradients, the greater one may expect the rate of plastic deformation of the earth's crust to be, and consequently (in the general case, the greater will be the tangential stresses in it which produce faults.

Although the direct causes of earthquakes are always the same -- faults -- and the origin of the latter may also be explained by the same physical (or rather, tectonophysical) causes, the geologic causes (in other words, the geologic conditions under which earthquakes occur) are complex and varied. This is due to the fact that the tectonic movements which generate faults in the depths, and thus also earthquakes, take place under sharply differing geologic circumstances.

Many geologists believe that the differences in the structure of the major structural elements of the earth's crust are caused by differences in the state of the material in the earth's depths, or to the different processes taking place here, or to both together. The ultimate result of these phenomena is that there is a fundamental change in the general structure of geosynclines which transforms them into platform areas.

The zones of intensive seismicity on the earth are connected not with any single region characterized by very specific structural features, but with various types of regions. These include both young folded zones, formed in the areas of recent geosynclines, and platforms, old as well as new, within whose territory in Neogene and Quaternary times intensive tectonic movements have reworked their former platform structure.

Hence earthquakes occur under conditions which differ in principle -- in media of various degrees of consolidation, as a result of tectonic movements of various natures and intensities, and at various depths, which probably involve different states of the material and different processes taking place at such depths, and so forth. It must naturally be supposed that all these circumstances cannot but affect the conditions under which faults, and consequently earthquakes as well, occur in the layers of the earth's crust. But the primary cause of the differences enumerated above we may properly consider to be the previous geologic history, which has been different in different regions.

The above remarks are based partly on general theoretical conceptions regarding the development of the earth's crust, and partly on generalizations drawn from extensive factual material on the seismology of the U. S. S. R. obtained in recent years, mainly by the researches in the Institute of the Earth's Physics of the Academy of Sciences of the U. S. S. R.

But before speaking of the importance of geologic history in understanding the different relationships between seismic and geologic phenomena, something must be said of the possible connection between the movements that cause earthquakes and their concrete geologic conditions. In theory, it is possible to distinguish two groups of earthquakes, of unequal importance.

The first group includes earthquakes whose foci are at very small depths, on the order of 3 to 5 km; in certain cases it is possible to associate these quite reliably with the movements of specific small surface structures which occur at very small depths. Since one does not in every seismic region also observe deeper earthquakes, caused by movements at greater depths, regardless of the development of small surface structures, it is sometimes impossible to distinguish with full precision whether the particular small earthquake is determined by movements of the small surface structure of by movements in the upper parts of deeper structures. For this reason the first group must be considered as one of particular and rare cases.

The earthquakes of the second, or basic, group are produced by movements taking place at various depths all the way to the bottom of the crust. This circumstance usually does not allow us to speak of a direct correspondence between the movements that carry earthquakes in their train and the structures visible at the surface, even if the particular structures are very large. There is stronger basis for arguing a connection between deep-seated movements and enormous structural complexes, zones (such as those of deep faults), vast areas characterized by recent movements of a single type and so forth. Probably the most correct view is that the overall structural background manifested at the surface is an indication of deep-seated processes that lead to an increase in seismicity.

The great variety of particular geologic factors with which, in similar conceptions, one might qualitatively associate different levels of seismic activity is well known: for example, sharp zones of contact between different large structural complexes with movements in opposite directions -- the movements that cause earthquakes frequently occur along these very zones; zones of large-scale faults, developing over a long time and maintaining their activity during several geologic epochs, or even periods; the case of an unconformable superimposition of a newly formed structure upon an earlier existing one, which occurs under intensified faulting at different depths; areas of differentiated intensive recent movements, which are sometimes reflected in the relief and sometimes not; and so on. A considerable quantity of the literature has been devoted to these questions (Belousov and Gzovskiy, 1954; Belousov, Kirillova and Sorskiy, 1952; Gzovskiy, 1957; Gzovskiy, Krestnikov et al, 1958; Goryachev, 1959; Krestnikov, 1955; Petrushevskiy,

1955a, 1955b; Popov and Rezanov, 1954; Rezanov, 1959, and others). Investigations by the Institute of the Earth's Physics Academy of Sciences of the U. S. S. R. have also established that the relationships indicated above are not completely identical in regions with essentially different geologic structures. As already mentioned, differences in the geologic conditions have a definite effect on the specific features of these relationships. Here the most important factor is the differences in the geologic history of the major (first-order) structural units.

Since the combined seismic and geologic conditions have been studied primarily in the western parts of the U. S. S. R. (west of the 90° meridian), the data cited below will relate mainly to these territories. In a number of cases, however, it has been possible to present examples from other regions also.

In the western part of the Soviet Union the relationships between the seismicity and the geologic peculiarities show definite differences between zones of Alpine folding, zones of young platforms (with a Paleozoic folded basement), and zones of platforms (regardless of the age of folding of their basement) which have been reworked by intensive tectonic movements in Neogene and Quaternary times.

A distinctive feature of the region of Alpine folding in the south of the U. S. S. R., which has been determined by the whole course of its geologic development, is structural transformation. By this the author means the repeated occurrence of intensive folding, the appearance of new and the renewal of old faults, etc. In an Alpine region a very active tectonic process is manifested whose duration is frequently reckoned in many geologic periods. A very typical feature is the fact that seismic activity is also associated with the manifestations of structural transformation: numerous earthquakes, some of great violence, take place here. As examples, one may cite the Caucasus folded zone (although earthquakes stronger than 8 points are not known within its area), the Turkmen-Khorasan folded system, whose northern margin forms the Kopet-Dag Range and, outside the Soviet Union, the Himalayas, the mountain chains of Asia Minor, etc.

In contrast to young folded regions, platforms are characterized by the absence of any transformation of the structures composing them, which develop in a single direction very slowly over a great length of geologic time. In the case of platforms with Paleozoic folded basements, an important factor is the inheritance of development, with a greater or lesser adaptation of the structural features of folding in the Mesozoic and Cenozoic mantle to the tectonic arrangement of the basement. Such inheritance is manifested to the greatest degree in the zones of the latest folding of the geosynclinal stage -- the late Paleozoic. Within the sedimentary mantle of the platform, this is reflected in the greater structural differentiation of such regions, which are also characterized by the greatest tectonic mobility. It is precisely in these areas that one most often observes an intensification of seismic activity; but because the mobility of even these regions is small on the whole, the earthquakes are here comparatively few in number and, as a rule, fairly weak. In rare cases their force somewhat exceeds 7 points. As examples we may take the Hercynian structures of the Urals and the Kyzyl-Kum mountains and, outside the U. S. S. R., the Hercynian structures of western Europe. Thus, in a platform zone, the intensification of the seismicity is affected by processes that began much earlier and at the present are manifested in very weak form.

The relationships between seismicity and geologic conditions are most complicated in platforms that have again been subjected to tectonic activity.[3] Very many earthquakes occur in regions that have undergone the latest folding in the geosynclinal stage and have thus, as a result of their inheritance of development, retained the greatest mobility in the platform stage. Since the general mobility here is much greater than in the corresponding regions of platforms (those located in the zones of the latest geosynclinal folding), some very violent earthquakes are known. Such a territory, for instance, is the Tien Shan -- at least, the part of it that lies west of the Talass-Fergana fault.

In those parts of reworked platforms that were stabilized in the early stages of geosynclinal development and which in the platform stage have been constantly less mobile, the primary criterion for an intensification of seismicity is the nature of the latest tectonic movements. If the movements show detailed differentiation and cause the appearance on the surface of small, intensively uplifted blocks coupled with subsiding blocks of equal size and intensity, the seismicity will be sharply increased. It is true that here relatively few earthquakes occur (fewer, evidently, than in areas of later stabilization), but the percentage of the most violent earthquakes is nevertheless higher. It is in such regions, rather than in the others, that earthquakes of 9, 10, or more, points are observed.

Regions characterized by recent uplift which is always in the same direction (of the type of

[3] This author believes that the term "reworked platform", which he has repeatedly used in other works as well, is not particularly happy. On the other hand, he cannot suggest a better one. The often-used term "activized platform" is even less successful. --Russian editor.

broad arches), within reworked platforms, although considerable in magnitude, are noticeably less active seismically. Such, for example, are the Altay region (the part within the U. S. S. R.), a number of districts of the Tien Shan (the Dzhungar Alatau, the Khan-Tengri cluster of mountains) and others.

Examples of highly seismic regions are the northern Tien Shan, with its extremely violent earthquakes (the Chilikskoye quake in 1889, the Kebinskoye quake of 1911, etc.) and the Baykal zone, in the northeastern part of which the very violent Muyskoye earthquake took place in 1957. This group should probably also include many regions of Mongolia, in which some of the strongest earthquakes in the world are known to have occurred (on July 9 and 23, 1905 in northern Mongolia and in 1957 in southwestern Mongolia), and also certain other regions of Central Asia.

Interesting information on the differences between the deep-seated processes in Alpine folded zones and in the territories of reworked platforms have been obtained in recent years through investigations of regional seismicity. These have been carries out in a number of districts of the U. S. S. R. with the aid of highly sensitive equipment at temporary seismic stations, and nave yielded precise determinations of the depths of the foci of weak earthquakes, down to several kilometers (in the observations of the continuously operating teleseismic network, the depths of the foci are indicated very roughly, as being merely within the earth's crust). Analysis of these data suggests (although only to the most general approximation) that the differences in the relationships of seismicity to geologic conditions, between zones of Alpine folding and reworked platforms, may be owing to the fact that the movements that generate earthquakes occur primarily in these regions at several different depths and in various layers of the earth's crust. In Alpine zones the movements evidently take place mainly at relatively small depths -- in the sedimentary and granitic layers -- whereas in reworked platforms they are at somewhat greater depths -- they are more concentrated in the basaltic layer.

Let us return to the factual data. In the area of Sochi, during half a year's time, the regional network determined the depths of several tens of foci of weak earthquakes; the overwhelming majority of these occurred at depths of 10 - 15 km or less, and only a few of them were deeper (Rustanovich, 1958).

Of 85 earthquake foci in the Akhalkalak highlands, determined in the years 1950 - 51, about 59 percent were at depths of 10 km or less, and only about 10 percent from 20 to 30 km (Tskhakaya, 1957).

Out of 125 foci of earthquakes in all the regions of the Caucasus whose depths were determined in the period 1950 - 1954, about 50 percent were 10 km deep or less; if the depth is extended to 15 km, the proportion increases to 80 percent (Tvaltvadze, 1957).

The foci of earthquakes in the Shemakh district (more than 30 in all), as determined in 1951, occurred at depths down to 10 km, and only individual cases down to 30 km (Koridalin et al, 1953).

A similar picture is seen in the Central Kopet-Dag. Almost all of a great number of earthquake foci in the Ashkhabad district determined in the year 1948 - 49 (after a violent earthquake in October, 1948) were at depths down to 12 - 15 km, and only a few at depths to 30 km. According to the data from the operations in 1953, the earthquake foci in this region were all within the depth range of 12 to 15 km (Rustanovich, 1957).

Thus, in all cases that have been considered, within the territory of the Alpine folded region in the southern part of the U. S. S. R. the great majority of foci of weak earthquakes occur at depths of 15 km or less, and about 50 percent of them down to 10 km. Consequently the movements along faults, which give rise to these earthquakes, occurred mainly in the sedimentary mantle and in the layer that geophysicists have called granitic (which, very likely, often includes the ancient metamorphosed rocks of the basement, which are also of sedimentary origin).

Thus far the only exception is the extreme western end of the Alpine structure of the Kopet-Dag. Here, along with numerous shallow earthquakes, a certain number of foci have been established at depths of 20 to 30 km or even more. But in moving to the adjoining Greater Balkhan, one sees a sharp increase in the number of foci at depths greater than 30 km; in the eastern part of the Balkhan, in fact, these amount to about half of the total number (Andreyev et al, 1954). A very noticeable increase in the depths of the foci in the Greater Balkhan, as compared to the Lesser Balkhan, is also indicated by the data from determinations of the weakest earthquakes, made by seismic instruments of especially high sensitivity (Belousov et al, 1952).

This example is particularly interesting because, in the opinion of a number of geologists, the Greater Balkhan belongs to the epi-Hercynian platform zone. In any case, even those who adhere to the theory that it is part of the Alpine region acknowledge that its structure differs sharply from that of the latter; the possibility has been suggested that the reason for this difference is the fact that in Paleozoic time, the Balkhan was part of a zone of Paleozoic folding.

As a result of studies of the structure of the earth's crust in this district, and comparisons of the information obtained with the data on depths of earthquake foci, it has become clear that although in the Lesser Balkhan and the Western Kopet-Dag, where the crust in thicker, the foci are mainly in the zone of Paleozoic sediments and the granitic zone, in the Greater Balkhan, where the crust has a smaller thickness, they are located chiefly in the basaltic layer and in the upper part of the subcrustal mantle (Kosminskaya et al, 1958).

In the northern Tien Shan, which by universal agreement belongs to the reworked platform zone, the foci of weak earthquakes, according to the data of G. A. Gamburtsev and P. S. Veytsman (1953), occur predominantly at depths of 15 - 25 km, and go down to 40 - 50 km and even deeper. This is true of both the foci located by the regional seismic network and the foci of the very weakest earthquakes, determined by high-sensitivity instruments in the Kungey and Zayliyskiy Altau regions and the northern part of the Issyk-Kul' basin.

By interpreting the seismograms of earthquakes in the Northern Tien Shan registered by the regional network during the period of 1950 - 1954, the depths of 122 foci were established. The majority of these were 15 - 20 km deep, others deeper, and a few at lesser depths (Vvedenskaya and Fogel, 1957). Most of these foci appeared to be located in the basaltic layer, the top of which here, according to seismic depth sounding, occurs at a depth from 10 to 20 km (Gamburtsev and Veytsman, 1953).

A slightly less clear picture emerges from study of the weak earthquakes in the Naryn district of the Tien Shan, carried out over a year and a half (1957 - 1958). This study indicates that many of the established foci were at depths down to 10 km, although many were also located in the range from 10 to 20 km and deeper than 20 km. The foci are very spottily distributed in depth: in some districts the great majority were shallower than 15 km (Dzhumgol); in others, foci at depths from 10 to 25 km predominated (the Kirgiz and Moldo-Tau ranges). Hence in the latter regions many of the earthquakes have their foci in the basaltic layer.

The eastern part of the Tadzhikistan depression (the Garmskaya oblast) has been given various structural interpretations, and has been variously assigned to the Alpine folded region, to the area of the reworked platform and to the border zone between them. For this reason it is not a suitable one in which to note the relationships between the distribution of earthquake foci in depth and the regional structure. On the other hand, the very fact of the exceedingly high degree of seismic activity in the Garmskaya oblast suggests that this phenomenon is also due to some exclusively geologic peculiarity. This may be determined by the fact that in the northern Pamirs and the Peter I Range, there is a sharp increase in both the thickness of the earth's crust as a whole (to 70 km) and in its granitic layer (to 40 km) -- meaning that this is again an exceptional case differing from the other districts of Central Asia (Kosminskaya et al, 1955). It may be recalled, finally, that in the neighboring region of the Southern Pamirs and the Hindu Kush there are deep subcrustal earthquakes (the depths of their foci being as great as 200 - 220 km); this in turn sharply distinguishes this region from the whole territory of continental Asia.

Nonetheless it must be said that more than a half the foci of the very many weak earthquakes in the Garmskaya region, registered by the regional network in 1955 - 1956, occur at depths of 12 km or less. Foci deeper than 25 km are known throughout the whole area, but they are few (Gzovskiy, Krestnikov et al, 1958). All these are in the granitic layer, which as mentioned earlier, is thicker here.

The data presented above, of course, can be considered as applying only to the most general tendencies. There is still too little material on the depths of the foci of weak earthquakes and their determinations are often still not accurate enough. Therefore it cannot yet be taken as a solidly established fact that the movements which produce earthquakes occur at different depths in Alpine zones and in reworked platforms; nevertheless this view may be put forth as a working hypothesis. It does not contradict the widespread theoretical conception of the differences between the deep-seated processes under Alpine folded regions and under more ancient platforms, and it agrees with certain seismo-geologic data mentioned above, which serve as an indirect confirmation of the hypothesis. It should be mentioned that the first observation of the greater "seismic activity" of the basaltic layer (as applied to the Northern Tien Shan) was G. A. Gamburtsev's (1956).

It is possible that these differences in the movements related to the depth in some measure also determine the unequal distribution, under different structural conditions, of the most violent earthquakes, as would follow from a statistical treatment of seismic data. On the reworked platforms of Central Asia, for instance, such earthquakes occur somewhat more frequently than in the Tethys zone of Alpine folding (Petrushevskiy, 1960). Over sixty years, from 1897 to 1957, about 12 very violent earthquakes (class "a" according to B. Gutenberg) were registered in both territories. Taking into account the enormous area occupied by the Alpine zone, it becomes clear that during this time interval the most violent seismic thrusts happened more frequently in the reworked plat-

forms than in the Tethys zone. The number of earthquakes of maximum force (the measure of their intensity, m, exceeds 7 3/4) on reworked platforms is also greater than in the Alpine zone of Tethys. In the course of fifty years, among 26 earthquakes of maximum force that occurred throughout the earth (Gutenberg, 1956), four were registered in areas of reworked platforms (July 9 and 23, 1905 in northern Mongolia; January 3, 1911 in the northern Tien Shan and December 16, 1920 at Hansui in China) and only two in the Tethys Alpine region (April 4, 1905 at Kangra and January 15, 1934 at Bihar-Nepal in India).[4]

The causes of the different manifestations of deep-seated processes which generate earthquakes in Alpine zones and reworked platforms can still be presented only as suggestions. Probably the determining factor is the greater degree of consolidation and rigidity of the platforms; their tectonic reworking cannot fail to be accompanied by especially violent fracturing and faulting, which will be reflected in the force of the earthquakes there. We have seen that the most violent of them are observed with somewhat greater frequency than in the Tethys zone of Alpine folding.

It is very difficult to believe, however, that the rigidity can have any effect on the depth of the movements that cause the occurrence of earthquakes on reworked platforms. It must rather be assumed that the basic factor is the great intensity of the processes taking place in the basaltic layer of these structural complexes. The greater thickness of the basaltic layer distinguishes them sharply from both ancient platforms (where, besides, the granitic and basaltic layers cannot always be separated) and from young platforms (Kosminskaya, 1958). Evidently the increased thickness of the basaltic layer beneath reworked platforms is the result of deep-seated processes that are new in these structures. Inasmuch as the granitic layer here retains about the same thickness as in young platforms, it may be thought that the new formation of basaltic layer and its growth take place at the bottom.

Perhaps the fact itself of the growth of the basaltic layer from the bottom is the reason for the development of movements primarily at greater depths in these regions than in Alpine zones. Another possible factor is the more rapid rate of these processes, which have taken place during the comparatively short period of time measured by the Neogene epoch and the Quaternary period.

[4] It is not impossible that the earthquake of August 15, 1950, which took place in the vicinity of Tibet, should also be included in the Alpine zone.--Russian Ed.

It would, of course, be premature to base any definite general tectonic conclusions on such suppositions. Nevertheless the author would like to remark that if these suggestions are correct on the whole, one interesting consequence of a general nature emerges from them. In speaking of the development of reworked platforms, it can be supposed that their transformation (breaking open) occurs from below upward, corresponding to some as yet unknown new features of the processes in the depths, which began in Neogene and Quaternary times in the subcrustal layer beneath a number of platform complexes.

One "bridge" that may be erected to connect the study of earthquakes with that of the general problems of tectonics is this new evidence of the possible value of seismo-geologic investigations for the study of tectonics.

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IGNEOUS ACTIVITY IN THE CHISHIMA (KURILE) ISLANDS[1]

by

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translated by Kinkiti Musya

ABSTRACT

The Chishima Islands are composed mainly of Neogene and Quaternary volcanics. Two cycles of volcanic activity are evident: a Miocene to Pliocene cycle and a Quaternary cycle, the break being marked by a period of crustal movement when the island arc was broken into three blocks now separated by deep channels. Volcanism in the northern and southern blocks are similar to their adjacent Kamchatka and Hokkaido regions while the middle block was characteristic of oceanic facies. A shift in rock type from generally acidic to generally basic is evident within each volcanic cycle. --M. Russell.

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INTRODUCTION

On account of the unfavorable geographic and physical conditions, the Chishima Islands[3] have been little studied geologically. Some explorational investigations made in the Meiji period [T.N. 1868-1912] and a reconnaissance survey of North Chishima by Prof. Sasa (1932) of Hokkaido University were the only surveys carried out hitherto. Papers by Sadakazu Tokuda, Akira Watanabe, and Masakichi Imaizumi, discuss the islands from the geomorphological point of view. Reports published since 1932 when the writer started the survey are cited in the end of this paper together with the above-mentioned papers.

The writer engaged in a geologic survey of the Chishima Islands for 10 years starting in 1932 as a project of Hokkaido University and the Hokkaido Government under the guidance of professors Suzuki and Harada and in cooperation with professors Ishikawa, Ishibashi, and Minato of Hokkaido University and Mr. Maso Saito of the Geological Survey of Japan. As mentioned above, the Chishima Islands are isolated, bleak, and numerous. Therefore the survey are exceedingly difficult and the writer can only scarcely outline the geology of the islands as a whole. The three islands of Onnekotan, Harumukotan, and Shasukotan and many adjoining islands have not been explored.

Geological and petrological data obtained as a result of the survey have not been studied in full. Consequently the following accounts of the igneous activity of the Chishima Islands should be considered tentative.

The writer wishes to expressed his thanks to professors Suzuki and Harada of Hikkaido University and the personnel of the Geological and Mineralogical Institute of the University for their guidance, suggestions, and cooperation.

GEOLOGY

In the Chishima Islands violent volcanic activity was displayed from Tertiary to Quaternary, and great quantities of material erupted. These formed thick deposits of detritus and rock, and were essentially the origin of the present islands.

The rocks constituting the Chishima Volcanic islands are tabulated in Table 1.

A granodiorite or diorite basement is overlain by thick deposits of post-Miocene volcanic detritus. Like the Tohoku district and southwestern part of Hokkaido, the deposits indicate continuous violent volcanic activity after the Miocene. Mudstone (shale) not closely related with volcanic activity occurs only on the two islands of Kunashiri and Etorofu.

Plutonic rocks constituting the basement are distributed in small areas and their age has not been confirmed, but the occurrence of Cretaceous gabbro in the Shikotan Islands suggests a relation. However, only the post-Tertiary igneous activity will be discussed in this paper.

As the petrologic studies of these eruptives is not yet completed, the writer does not here use exact rock names but simply the terms acidic neutral, and basic rocks. Only generali-

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[1] Jubilee Publication in Commemoration of Professor Jun Suzuki, M.J.A. Sixtieth Birthday (1956) p. 237-252, 1958.

[2] Sapporo Branch, Geological Survey of Japan.

[3] In this paper the Chishima Islands indicate only the main zone excluding the Shikotan Islands which belong to the fore zone.

Table 1. Summary of the geology

Geologic age		Stratigraphy	Principal rocks	Sequence of eruption	Principal lithologic character
Quaternary	Alluvium	Alluvial deposits	Sand, gravel, and clay	Taketomi-jima type eruptives Araito type eruptives	Basic ~ neutral rocks Basic ~ neutral rocks
	Diluvium	Terrace deposits Toshimoe beds	Sand, gravel, and clay Volcanic detritus	Iwo-yama type eruptives	Neutral ~ basic rocks
Neogene	Pliocene	Shana beds	Tuff, agglomerate (intercalated with lava and tuffaceous sandstone)	Pliocene eruptives	Neutral ~ basic rocks
	Miocene	Rubeshi beds Iruribushi beds	Mudstone (shale) Green tuff, agglomerate (intercalated with propylite and tuff breccia)	Miocene eruptives	Neutral ~ acidic rocks
Pre-Miocene				Granodiorite Diorite	

zations are possible with regard to distinctions of lithology on the basis of age.

VOLCANIC ERUPTIVES

The Chishima Islands are composed of various volcanic eruptives which are products of volcanic activity displayed continuously from Tertiary to the present. The period of eruption, mode of occurrence, and principal lithologic character of these eruptives are shown in Table 2.

The Neogene eruptives (I, II) which consist mainly of agglomerate and tuff are frequently intercalated with or overlain by lava. In volcanos consisting of Neogene eruptives, usually erosion obliterated the volcanic forms. Volcanos consisting of Iwo-yama type eruptives (III) also have been dissected, but the forms of volcanos are distinctly observable. In these eruptives, alluvial ones (IV) are partially discernible, but as it is difficult to distinguish one from the other, for convenience both are treated as (III). Araito type eruptives (IV) date to the Alluvial epoch, consequently dissection has not considerably progressed, and the forms of volcanos remain perfect. The representative

TABLE 2. Volcanic eruptives

Geologic age		Sequence of eruption	Volcanic eruptives	Mode of occurrence	Principal lithologic character
Quaternary	Alluvium	V	Taketomi-jima type	Lava Other detritus	Basic ~ neutral rocks
		IV	Araito type	Lava Other detritus	Basic ~ neutral rocks
	Diluvium	III	Iwo-yama type	Lava, agglomerate Other detritus	Neutral ~ basic rocks
Neogene	Pliocene	II	Pliocene eruptives	Lava Agglomerate Tuff Dike	Neutral ~ basic rocks
	Miocene	I	Miocene eruptives	Lava Agglomerate Green tuff Tuff-breccia Propylite	Neutral ~ acidic rocks

volcanos in the Chishima Islands belong to this kind and they are of well-formed Konide or Tholoide type. Taketomi-jima type eruptives (V) typify historically recorded eruptions principal examples of which are Taketomi-jima and Harumukotan-jima.

Green tuff and associated acidic rocks occur in the lower part of Miocene eruptives on Kunashiri and Etorofu Islands. However, the upper part gradually passes into neutral agglomerate and lava. Pliocene eruptives mainly consist of neutral rocks, but grade into basic in the higher portion. Dikes intruded in this period are more diverse than eruptives and involve acidic, neutral, and basic rocks. The dikes are considered to be closely related with Neogene mineralization in the Chishima Islands.

Quaternary eruptives are mainly neutral rocks with relatively few basic rocks involved, although Alluvial eruptives, show a gradual predominance of basic rocks.

The above changes of lithologic character are shown also in Table 3. Only 17 analyses are represented but a general tendency is evident.

Characteristics of Igneous Activity by Geologic Age

Roughly speaking, there were two cycles in the volcanic activity of the Chishima Islands; one ranged from Miocene to Pliocene, the other extended from Quaternary to the present. During each cycle a change from acidic to basic rock is evident.

Characteristics of Igneous Activity by Area

The Chishima Islands are composed of more than 10 islands arranged en echelon, exhibiting a general arcuate form convex to the Pacific. The islands can be divided into three areas, as shown in Table 4, on the basis of topography, particularly the submarine relief. The channels between the islands are generally scores of meters to several hundred meters deep, but the Mushiru Strait and North Uruppu Channel which divides the three areas are 1,800 m deep. In the South Chishima area and North Chishima area, respectively, adjacent to Hokkaido and Kamchatka, the sea is relatively shallow, but the Middle Chishima area, the sea is deeper. The difference of the depth may be attributable to considerable upheaval in the north and south and much less upheaval or partial subsidence in the middle.

TABLE 3. Lithologic character of the volcanic rocks

Age	Sequence of eruption	Rocks	Locality	SiO_2 percent	[Lithology]
Alluvium	V	Olivine-anorthite basalt	Araito Is. Taketomi Is.	50.29	Lava
		Olivine-anorthite basalt	Araito Is. Taketomi Is.	50.35	Scoria
		Two-pyroxene andesite	Harumukotan Is.	60.67	Pumice
	IV	Olivine basalt	Summit of the somma of Araito Is.	50.83	
		Two-pyroxene andesite	Jigoku-yama, Uruppu Is.	61.68	
		Basalt	Atosa-nupuri, Etorofu Is.	49.89	
		Pyroxene andesite	Rausu-san, Kunashiri Is.	57.66	
		Two-pyroxene andesite	Takaranuma volcano, Kunashiri Is.	64.28	
Diluvium	III	Two-pyroxene andesite	Iwo-yama, Uruppu Is.	60.43	
		Olivine-two-pyroxene andesite	Daiba-yama, Uruppu Is.	55.52	
		Olivine-two-pyroxene andesite	Gokuraku-yama, Uruppu Is.	57.86	
		Two-pyroxene andesite	Kashiwabara Bay, Horomushiro Is.	61.51	Kitanodai lava
Pliocene	II	Hypersthene andesite	Kokutan Cape, Shumushu Is.	59.75	
		Two-pyroxene andesite	Takasaki, Uruppu Is.	58.13	
		Basaltic andesite	Tokotanhama, Uruppu Is.	55.61	Dike rock
		Dacite	Zaimoku-iwa, Kunashiri Is.	69.64	Dike rock
		Two-pyroxene andesite	Tengu Cape, Horomushiro Is.	61.19	

IGNEOUS ACTIVITY

Activity by geologic age, areas, and forms of volcanos is here considered.

As described above the basement of each island consists of Neogene eruptives. Conse-

TABLE 4. Areas and channels of the Chishima Islands

Area	Islands belonging to the area	Channel
North Chishima	Shumushu - Shasukotan	
		Mushiru Strait
Middle Chishima	Matsuwa - Shimushiru	
		North Uruppu Channel
South Chishima	Uruppu - Kunashiri	

quently, in South and North Chishima where considerable upheaval occurred, acidic to neutral Miocene eruptives are exposed, but in Middle Chishima where upheaval was in a less degree, only neutral Pliocene eruptives are distributed.

Concerning Quaternary eruptives, the same relationship as the above-mentioned Tertiary eruptives is noticed. That is, North and South Chishima are composed mainly of neutral rocks, but Middle Chishima consists mainly of rather basic neutral rocks or basic rocks.

The following interesting facts are noticed in Alluvial eruptives (IV) in North and South Chishima:

a) Complex volcanos which were built up in the older volcano group by the revival of the older volcanos forming the mountain ranges en echelon mostly consist of neutral rocks (Rausu-yama, Jigoku-yama).

b) Isolated volcanos (mostly of Konide type) separated from the main row of the mountain range en echelon are composed of basic rocks (Araito-dake, Atosa-nupuri, Chacha-dake).

However, in Middle Chishima, both volcanos on the main row of the mountain range en echelon and those separated from the main row are composed mostly of basic rocks.

In Recent, historically recorded, eruptives (V) a relationship similar to (IV) above is found. That is, Taketomi-jima built up in a point separated from the main row of the mountain range en echelon consists of basic rocks, and Harumukotan-dake which played an active part as a result of the revival of the older volcanos constituting the mountain range en echelon is composed of neutral rocks.

Characteristics of Igneous Activity by Volcanic Form

Neogene volcanos generally have been considerably dissected and the forms of volcanos are indiscernible, so only Quaternary volcanos are discussed here. As shown in Table 5, the relationship between forms and lithologic characters of the younger volcanos in North and South Chishima is slightly different from that in Middle Chishima.

The volcanos of Konide type in each area are composed of basic rocks, but as to the complex volcanos and volcano groups, the rocks in Middle Chishima seem to be basic as compared with those in other two areas. In a volcano having a large caldera there is no considerable difference between the somma and the central cone in lithologic character, but in a volcano having a small caldera or an explosion crater there is a general tendency for the central cone to be highly acidic.

CONCLUSIONS

The mode of igneous activity of the Chishima Islands in the Neogene is somewhat different from that in the Quaternary.

In the Neogene, volcanic activity was actively from Miocene to Pliocene, great quantities of volcanic detritus were hurled out, and thick deposits were formed. Roughly speaking, there were following changes in lithologic character throughout the region. Acidic rocks ⟶ neutral rocks ⟶ basic neutral rocks or basic rocks. In the end of the Neogene volcanic activity became somewhat feeble and abundant lava of basic neutral rocks or basic rocks poured down. These phenomena being common to the three areas, the Chishima Islands are considered to have been under similar geologic conditions on the whole in the Neogene.

Neogene igneous activity was followed by an arcuate upheaval and the formation of a folded zone probably due to changes which occurred in the end of Pliocene, and the large Arcuate Chishima Islands which resemble the present topography were formed. In this case, considerable upheaval took place in the northern and southern areas, but in the middle area upheaval was not as severe or it may have subsided partially. Thus Middle Chishima was separated from North and South Chishima by two channels 1, 800 m deep, and though the three areas form an arcuate series of islands the middle area exhibits geologic environments

TABLE 5. Form and lithologic character of the volcanos

Area	Volcanos of Konide type	Complex volcanos - Volcano groups most of which are of Tholoide type
North Chishima	Basic rocks	Neutral rocks
South Chishima	Basic rocks	Neutral rocks
Middle Chishima	Basic rocks	Neutral rocks (basic) - basic rocks

somewhat different from those of the other two areas. North and South Chishima are connected with and resemble the Kamchatka Peninsula and Hokkaido both of which belong to an upheaval zone in the margin of the continent, whereas, Middle Chishima rather resembles an oceanic facies.

After the Chishima zone has been divided into areas of different geologic environments Quaternary igneous activity was displayed in each area. Consequently, in the Quaternary mainly neutral rocks were erupted in North and South Chishima and mainly basic rocks were displayed in Middle Chishima.

The Alluvial igneous activity is rather different from that of the Neogene and Quaternary. In North and South Chishima, abundant neutral rocks are found in volcanos built up by the revival of older volcanos which constitute the mountain ranges en echelon and volcanos of Konide type built up in places separated from the main row of the mountain ranges en echelon are composed of basic rocks. However, in Middle Chishima, volcanos mostly consist of basic rocks irrespective of position.

In the Chishima Islands consisting of an arcuate series of islands the following facts are particularly noteworthy.

1) The lithologic character of eruptives following block movements in this region, in other words, the Quaternary eruptives varies fairly distinctly with area.

2) Lithological character of the Alluvial eruptives differs within one and the same area according to the positions of volcanos.

3) The relationship between the forms of volcanos and lithologic character shows some regularity.

It is considered that these facts are useful as a clue to the studies of igneous activity and the origin of igneous rocks.

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OUTLINE OF THE GEOLOGY OF KOREA[1]

by

Iwao Tateiwa

• *translated by the author* •

CONTENTS

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INTRODUCTION

It probably has been known since the first publication on the geology of Korea by C. Gottsche in 1886, that Korea strikingly differs in geology from that of Japan, but there are many similarities between Korea and South Manchuria or North China. Many problems remain unsettled in regard to detailed comparison, however, even at the present state of progressed knowledge of the geology of these countries. For instance, much remains uncertain as to the stratigraphic relationship between the subdivisions of the geological system in Korea and those of South Manchuria or North China, even on correlation between major stratigraphic units.

In this paper the writer intends to give a general idea of the sequence of geological events to which Korea was subjected. For this purpose a generalized table, compiled on the basis of up-to-date information together with newly revised speculations by the author, of the geology of Korea is given at the end of the paper.

Before discussing the compilation of the table, however, I intend to present the principal differences and similarities in the geology of Korea and Japan, and then of Korea and South Manchuria or North China. Also, to discuss to some extent the important problems on the stratigraphy and crustal movements of Korea, for such comparisons and discussions, together with the table, may be synthetically available for instructive accounts of the outline of geology, not only of Korea, but of a vast area in eastern Asia.

COMPARISON WITH JAPAN

Comparing the geology of Korea with that of Japan, we can easily find marked differences between the two countries, first in the areal distribution of dominant rocks and then, examining in detail, in the sedimentation environments, the crustal movements, the epochs, as well as lithological characteristics of igneous activities, etc.

a) In Korea Mesozoic or older rocks, including neo-granites which are considered to be of a stage ranging from the later Cretaceous to the beginning of the Tertiary, are found extensively distributed. Expecially Precambrian granite gneisses and crystalline schists together with granites, the majority of which may belong to the neo-granite referred to above, occupy extensive terrain covering over one half of the whole area of Korea, while Tertiary or later rocks are found occupying isolated and narrow areas, or thinly covering older rocks.

Terrain of eruptive rocks of the Tertiary or younger is of course much narrower than that of Japan. In this connection, however, it may be interesting to note that these are two characteristics of Korea which are unique to Japan, besides the fact that andesitic rocks, very common and widespread in Japan, are limited in distribution to far narrower area in Korea.[2]

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[1] Translated from the Japanese: Geology and Mineral Resources of the Far East, Korea III-1, Stratigraphy, prepared under the auspices of the Compilation Committee of the Geology and Mineral Resources of the Far East, Tokyo Geographical Society, 1953; translation prepared for Engineer Intelligence Division, Office of the Engineer, Hq. U.S. Army Japan, May 1958; edited by Carol Broline, U.S. Geological Survey.

[2] Among the Cenozoic lavas in Korea which have been generally known under the name of basalt, there are some which are two-pyroxene andesite. Except for these, andesite is found mainly in association with the Tertiary beds in the Yŏngil district of North Kyŏngsang-do. The andesitic rocks in Korea are rather common and widely distributed in the terrain of the Cretaceous Shiragi series.

First, multifarious alkaline volcanics, probably late Tertiary or Pleistocene, cover some extensive areas in the northeastern part of Korea, forming as a whole the essential portion of a special petrographic province in eastern Asia.

Next, there are extensive terraces of basaltic lavas in various places in North Korea, one of which extends far into Manchuria as a basaltic lava plateau surrounding Mt. Paektu. The outpouring of these basic lavas seemingly suggests some genetic connections with a crustal condition of the Tertiary period under which the land was diversely disjuncted by normal faults and tilted.

b) In sedimentary environments there are also various differences worthy of special notice between Korea and Japan. Korea was subjected to large-scale transgressions of oceanic water at least two times during the Precambrian and two times in the Paleozoic, and thick accumulations of marine sediments resulted. But, after the latest sea retreated from Korea in the late Paleozoic the environment was greatly changed and the land was never covered extensively by marine water, although it was often covered by more or less extensive lacustrine or partly littoral water during the Mesozoic, and then only the marginal terrain of the land was under lacustrine, lagoonal, or rarely littoral water. In Japan, however, extensive terrain was almost incessantly under sea water from the Gotlandian to the Tertiary or later.

c) Of course, paleogeographic changes of land and water were not the same in Korea and Japan; for instance, the upper Paleozoic sediments of the Kitakami mountainland in northern Japan are interrupted by stratigraphic hiatuses, four or so in number, while in Korea the upper Paleozoic Heian system shows only one hiatus indicating the Uralian interval, as is suggested quite paleontologically. The Tertiary sediments of Japan generally have such variable rock facies and are so diversely divided by frequent unconformities, according to basins, that it seems to be one of the most difficult and laborious tasks for the Japanese geologists to work out stratigraphic relations among these beds in different basins, and difficulties are often met with even during the stratigraphic study of a single basin. Similar diversities in paleogeographic changes according to places and times may be found in the Mesozoic stratigraphy in Japan. So far as geology of the pre-Tertiary periods is concerned, diversity and frequency of paleogeographic changes in Korea were in general minor and the changes themselves seem to have occurred in more extensive areal units than in Japan.

d) In Korea Jurassic strata, or strictly speaking middle Jurassic, or older, were strongly folded and thrusted, and often exhibit "schuppen" structures due to repeated thrustings. Younger strata, however, are more or less tilted with angles dipping lower than 30°, or nearly horizontal, although these are frequently disrupted by faults, dominantly normal, and exhibit insignificant folding.[3]

From these comprehensive facts a conclusion may be reached that Korea was dominantly under compressive stress until the middle Mesozoic, but subsequently converted into an area of an alternative condition under which the land was tilted, block by block, accompanied in some cases by subordinate folding of strata. The present geomorphologic features of Korea are considered to have largely originated in these block movements.

The crustal movements thus suggested by studies of Korean geology may be most appropriately classified according to phases of movements as follows:

1) Orogenic movements of the early Mesozoic (post-Heian and pre-Daidō), namely the Shorin disturbance, as defined by T. Kobayashi. (1930). The movement may be comparable in age to the Akiyoshi disturbance in Japan and a little later than the Tsingling movement in North China, which has been interpreted as a prolongation of the worldwide Hercynian movement.

2) Orogenic movements of the late Jurassic period (post-Daidō and pre-Rakuto), namely, the Taiho disturbance as defined by E. Konno (1928). The disturbance can be correlated to that of the Oga phase of the Sakawa orogenic cycle in Japan, and may represent an earlier phase of the East Asiatic Tenshanian movement in Korea.

3) Two phases of subsidence of inland (?) basins in which Flysch-type sediments of the Rakutō and Shiragi series were deposited, accompanied by a widespread effusion of intermediate or rather basic lavas in the Shiragian phase. Both may also represent phases of the Yenshanian movement.

4) Block movements closely related to the large-scale intrusion and extrusion of acidic rocks of the Bukkokuji group; subsidence of the Tsushima basin, in a strict sense, in which thick sediments of the Taishu group were laid down, is an event which may be included in the same phase as the block movement. The movement may be interpreted as a prolongation of

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[3] Rare cases of overthrusting, shown by old massifs thrusted at low angles over the later Mesozoic Shiragi series, are seen in several places in the northern part of North Kyŏngsang-do, and some faults in the Sinian direction (NE-SW) in South Korea are observed to be the reverse.

the Yenshanian movement of China, and, as a whole, roughly comparable in age to the North American Laramide Revolution.

5) Block movements of the middle Tertiary, the essential portion of which probably began in the Oligocene and lasted to a certain stage of the Miocene (pre-Ennichi). The movement resulted in local extrusions of basaltic and some other lavas, and a conspicuous warping of the Miocene terrain in the Kilchu-Myongch'ŏn district, N. Hamgyŏng-do.

The movement may have been a prolongation of the Nanling movement of China which is considered to be a part of the Himalayan movement. In Korea, however, it seems to have been more closely related in genesis to the Ōyashima movement, in which upward pressure folded the Japan Archipelago, and may also be designated as a part of the Himalayan movement.

Of these, the former two are separated by an intervening phase of subsidence of inland basins where terrestrial sediments of the lower Jurassic Daidō series were deposited. The sediments reached over 2,600 m in thickness in South Ch'ungch'ŏng-do of South Korea.

The fourth movement was followed by a stage of widespread peneplanation, the remnants of the peneplain of this stage being observable in limited patterns on the Kaema plateau and on tops of high mountains in various districts of Korea. It may be correlatable with the stage of peneplanation in North China, well known under the name of Peitai.

Phases 2, 3, and 4 are undoubtedly closely related to each other in time succession and may represent as a whole the Yenshanian movement in Korea and its prolongation, the Yenshanian movement in Korea which is defined as being correlative in time with the Sakawa orogenic cycle in Japan by T. Kobayashi. Summarizing what has been emphasized concerning crustal movements in Korea, the author briefly outlined his opinions as follows:

A. Short disturbance

B. Taihoan disturbance, preceded by a phase of subsidence of inland basins

C. a) Rakutōan phase
   b) Shiragian phase

D. Bukkokujian disturbance, followed by a stage of widespread peneplanation, namely the Peitai stage. The disturbance may be roughly correlatable in age with the North American Laramide disturbance.

E. Nanling movement, a part of the Himalayan (Ōyashima) movement.

(B–E: Yenshanian and its prolongation)

Except for the epeirogenic movements to which Korea was often subjected, with the striking Pleistocene or later uplift as the final phase, crustal movements are suggested to have occurred in the Precambrian. The characteristics of these movements, however, are too obscure to me.

A noteworthy phenomenon is that the Lower Cambrian to Triassic strata in Korea are found with parallel bedding planes, although these are interrupted by one or two stratigraphic intervals. Moreover, so far as is known to me, the Lower Cambrian beds lie disconformably against the late Proterozoic-Sinian system which, in turn, undoubtedly rests disconformably upon the complex of crystalline schists of uncertain age in the terrain between Sunch'ŏn and Sukch'on and in the eastern part of Songch'ŏn-gun, South P'yŏngan-do. The facts suggest that no conspicuous orogenic movements occurred in Korea from late Proterozoic to a certain stage of the Triassic, and in South P'yŏngan-do, at least, the quiescent age goes back still farther.

e) Volcanic activity in historical times is very insignificant in Korea. There are only two reliable legends which convincingly reveal historical volcanic activity. According to these, the dormant volcano Cheju-do (Quelpart Island) became active and exploded in the years 1002 and 1007, and basaltic lavas poured out both times.

In addition to the above, there are less convincing legends which suggest volcanic activities of Paektu-san on the border between Korea and Manchuria in the years 1597 and 1702. The 1702 data reveal the explosion of that mountain and accumulation of whitish volcanic ash from it.

Korea has no active volcanos at present, and this fact, together with the lower frequency of earthquakes, is of course one of the striking differences in geology between Korea and Japan.

At this time a few words must be added concerning the earthquakes of Korea. Ancient records from various sources in Korea show that earthquakes occurred on 1,661 days during the 2,000 years since the time of the three dynasties. Approximately 40 were more or less violent and resulted in destruction of some buildings or injured people, although they were evidently not as destructive as those often experienced in Japan.

The actual number of earthquakes in Korea may be larger than the above figure, for it is not improbable that two or more earthquakes were experienced on the same day; some such records of earthquakes have accidentally been lost, which is highly probable judging from the past history of Korea; and that all earthquakes were not necessarily recorded, for instance, in the days of the first dynasty. Nevertheless,

it is beyond doubt that the frequency of earthquakes in Korea is far lower than in Japan. In fact, I can report only one felt earthquake in Korea during my 28 years' stay there, which I experienced at Changgi, Yongil-gun, on the eastern coast of North Kyŏngsang-do.

f) Last, the important mineral resources of Korea naturally differ from those of Japan. First of all, it is to be noticed that Korea lacks oil fields and sulphur deposits. Coal in Korea is represented by anthracite from the upper Paleozoic Heian system. The country is extremely poor in resources of tin, manganese, antimony, and mercury.

On the contrary, Korea is comparatively rich in tungsten, magnesite, apatite, graphite, mica, barite, fluorite, talc, cyanite (together with sillimanite and andalusite), monazite, zircon, allanite, beryl, various lithium minerals, etc. Especially characteristic of the country are the rich deposits of magnesite and tungsten, which may be unique in the world; numerous deposits of crystalline and earthy graphite, of which total annual production is often the highest in the world; and extensive placers of heavy minerals which are generally rich in monazite and zircon in close association with fergusonite, samarskite, columbite, gold, etc. There seems to be no great difference between Korea and Japan in the amount of ore reserves of the remaining kinds of important minerals.

Finally, it must be noticed that in general the origin of mineral deposits in Korea was much earlier than in Japan, because the most important minerallo-genetic epoch is believed to be approximately later Mesozoic, namely the epoch of acidic rocks of the Bukkokuji group, the majority of mineral deposits in Korea, either metallic or non-metallic, probably being either the same age as the Bukkokujian or older.

COMPARISON WITH SOUTH MANCHURIA AND NORTH CHINA, WITH SPECIAL REFERENCE TO PRECAMBRIAN STRATIGRAPHY IN KOREA

As can be seen on maps of eastern Asia, the distance between Korea and Japan is not necessarily great in comparison with that between Korea and North China, or even between northern and southern Korea. Even so, the geology of Korea differs strikingly from that of Japan, as already stated, while there are many similarities in the geology of Korea and South Manchuria or North China. Such a distinct contrast revealed in the geology on both sides of Tsushima Strait (Western Channel) seems to have depended largely upon the unique situation of the arcuate mountains, including Japan, occupying the periphery, and, in consequence, unstable portion of the Asiatic continent throughout long ages. In contrast, in Korea, South Manchuria, and North China, the geological history of the interior basins of the arcuate mountains, more or less drawn back from the peripheral zone of the continent, has been strikingly similar throughout ages, as their geology indicates.

It is by no means unusual, therefore, that there are so many similarities in the geology of Korea, South Manchuria, and North China. In fact, the majority of the geological differences between Korea and Japan as mentioned previously, seem to correspond to the geological similarities between Korea and South Manchuria or North China.

The most striking similarities are shown in the thick sediments of the upper and lower Paleozoic and the upper and lower Proterozoic, all occurring successively as the four major units in the stratigraphic columns in every country under consideration. The sediments of these major units in Korea are so similar in rock sequence, lithological nature, and fossils, if any, to corresponding sections in South Manchuria or North China that they are safely interpreted as portions of the widespread sediments of the common large-scale transgressions on these countries.

Diverse terms have been proposed, however, for these stratigraphic units according to countries or to authors, which were unavoidable because of imperfect knowledge in the past, although it is desirable to use terms common to all of these countries.

For the purpose of unification of terms, the writer selected terms available from those which have already been proposed for the above four stratigraphic units in these countries. The four terms are as follows:

Heian system (middle Carboniferous-Triassic)
Chōsen system (Lower Cambrian-Middle Ordovician)
Sinian system (upper Proterozoic)
Wutai system (lower Proterozoic)

Of these, the term Heian was proposed by R. Kodaira (1924) and the Chōsen by K. Inoue (1907), both are well known among Japanese geologists who are interested in the Paleozoic stratigraphy of eastern Asia. The Sinian is here taken in the sense recommended by A. W. Grabau and applied to the Shōgen system, idiomatic term in Korea; and the Wutai, an old term by F. von Richthofen (1882) for all of the metamorphosed sedimentaries, represented by the Matenrei system in the northeastern part of North Korea, the Yokusen system diagonally traversing South Korea, and the Jōsuiyo series scattered in the western part of N. P'yŏngan-do. The three complex metamorphic rocks in Korea may be roughly con-

temporaneous with one another.

The term for the oldest complex, constructed of crystalline schists, in Korea, the Rensen system, by S. Kawasaki[4] is being tentatively retained. S. Nakamura and S. Matsushita (1940) proposed another term, the Keirin system, for the Korean complex including all of pre-Sinian metamorphosed sedimentaries, and considered its age to be Archean. Aside from the chronological interpretation of the term by these two authors, the term may be conveniently available for any complex of metamorphosed sedimentaries in Korea which cannot be differentiated into upper and lower Proterozoic.

According to some authors the Sinian system is divisible into two parts by a stratigraphic hiatus in its upper portion. If the hiatus is as great as S. Matsushita (1947) insists, the system should be divided, as has already been done by that author, into two parts. Matsushita proposed that the Sinian, in a strict sense, be used for the upper part, and that the old term, Huto, proposed by B. Willis and E. Blackwelder in 1904, be used for the lower part.

A few paragraphs will be added concerning the Paleozoic stratigraphy in Korea. It is known to be one of the striking phenomena in the stratigraphy of eastern Asia, that the middle Carboniferous sediments rest disconformably upon the Middle Ordovician limestone throughout the vast area comprising Korea, South Manchuria, and North China. In Korea, however, existence of Gotlandian terrain has been suggested since 1934, when S. Shimizu, K. Ozaki and T. Obata[5] reported the unexpected discovery of fossils from limestone pebbles of the basal conglomerate of the Lower Jurassic Daidō series near Kyomip'o Hwanghae-do. From these fossils, the authors have identified 18 coralline species and 4 species of cephalopods, and considered the fauna to suggest the Gotlandian age.

The Gotlandian terrain fossils, are supposed to have existed not so far from Kyomip'o, although no proof has been discovered as yet.

In this connection, it is most interesting to refer to a recent paper by T. Yamaguchi (1951), reporting a discovering of doubtful fossils yielded from a thin bed consisting of arenaceous slate and limestone in Kumch'ŏn-gun, Hwanghae-do. According to him, the collection contains a form comparable to *Monograptus prioden* Bronn, and some forms which can be assigned to a certain species of *Cypridea*, and the meagre collection as a whole suggests the Gotlandian.

The fossil-bearing bed is intercalated in a thick series consisting largely of phyllites with or without pebbles, offretite-bearing clay slate, quartzite, and limestone. Except for the fossils discovered by Yamaguchi, there has been no age measurement available for the thick series, although the series was formerly assigned to the Kyūzan formation of the Heian system because of its inferior anthracite seams, and later to the Sinian system because of its lithological and stratigraphical resemblances to the latter. According to Yamaguchi, therefore, the Kyūzan formation or a part of it is probably Gotlandian, and a part of the Rensen system, namely, its upper portion by S. Kawasaki, is considered to be far younger in age, for that portion of the Rensen system rests, showing no evidence of tectonic contact or unconformity, upon the thick beds of pebbly phyllite occupying the uppermost part of the Kyūzan formation.

Taking all the matters reported by Yamaguchi into consideration, stratigraphic interpretations already reported concerning the Sinian and the Rensen systems in Kumch'ŏn-gun and its surrounding territory may be inevitably revised to some considerable extent. In the limit of present knowledge, however, the writer hesitates to follow him in considering the entire Kyūzan formation or a part of it to be of the Gotlandian and the Rensen system in part, younger in age, although he cannot deny the probability of existence of the Gotlandian terrain in Kumch'ŏn-gun.[6]

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[4] The term was probably adopted in the explanatory text for the geological map of Korea shown at the memorial exhibition of the fifth anniversary of the new administration of the Government-general of Chōsen (Seoul) in 1914.

[5] These authors had considered the conglomerate with the fossiliferous limestone pebbles as Gotlandian sediments, but soon after the publication of their paper T. Kobayashi visited the locality and affirmed the younger age of the conglomerate as mentioned (Kobayashi, T., Is the limestone conglomerate at Kyomip'o Gotlandian sediments?: Jour. Geol. Soc. Japan, v. 47, p. 362.).

[6] The fossil bed in question is found in a broad shear zone trending from east to west. In the Chŏngok-ni district in the southern part of Yonch'ŏn-gun a little to the south of the shear zone, there is Lower Jurassic shale with plant fossils, together with conglomerate. According to my observation, the Jurassic beds are intercalated as more or less narrow bands in the complex of mica-schists which belong to the Upper Rensen system by S. Kawasaki. The Jurassic beds are generally sheared and often phyllitic, the plane of foliation being parallel to the general trend of the Jurassic bands and at the same time to the foliation of the mica-schists. Tectonic contact between the Jurassic bands and the mica-schists is often verified, but exact position of the contact is often obscure because of the complicated phyllitic structure of both the Jurassic bands and the mica-schists. (Continued)

The other question remaining for future study is concerned with the existence of Devonian sediments in Korea, which was suggested by a few forms of coralline fossils reported by H. Yabe and T. Sugiyama (1939), from Ch'ŏnsŏng-ni, Sunch'ŏn-gun, South P'yŏngan-do, where both the Heian and the Chōsen systems are exposed; the fossils are reported to have been yielded from a limestone block on the ground. In this case also, the limestone strata from which the fossils were derived have not been disclosed.

In South Manchuria (Noda, M., 1952) a bed of limestone conglomerate over 10 m in thickness is found between the Middle Ordovician limestone and the Middle Carboniferous Penchi series in disconformity to both series. In Shantung province, North China (Noda, M., 1952)[7] a similar bed disconformably rests on the Middle Ordovician Chenan limestone. No fossils have been discovered as yet from these beds, however.

As to the stratigraphic correlation of rocks in Korea with those in South Manchuria, diverse views have been published by various authors and many questions remain unsolved for future study. However, it seems to be quite reasonable to correlate the three divisions of the Korean Sinian system in the Grabau sense, namely, the Kuken, the Shidōgu, and the Chokken with the Nanshan, the Kuantung and the Tahoshangshan of the corresponding section in South Manchuria.

The Maternrei system, one of the representative complex of the Korean Wutai system, may safely be correlated with the Liaho system of South Manchuria, the Wutai of North China, and the three divisions of the Matenrei system, the upper, the middle and the lower, by Y. Kinosaki (1932) with the Kaiping, the Tashihchiao, and the Hsiang-shuitzu series of the Liaho system in South Manchuria, respectively.

The South Manchurian Hsiho series was recently correlated with the Tahoshangshan by S. Matsushita (1952) and R. Saito (1952). There are, however, some doubts about the stratigraphic interpretation of the Hsiho on the opposite side of Chasŏng district in Korea beyond the upper reaches of the Yalu River (Amnok-kang) for the Chōsen system, with fossils, in the adjacent Kanggye and Huch'ang districts rests directly upon the erosion surface of granite gneiss and crystalline schists without any intervening Sinian sediments.

Similar beds found in the Chasŏng district, which are no doubt a continuation of the so-called Hsiho series on the opposite side of the Yalu River, have been compared with the Chōsen system by K. Nakamura (1942) and T. Kobayashi (1952). It seems to me more probable that the series in these districts on both sides of the Yalu River corresponds either to the Chōsen system, as K. Nakamura and T. Kobayashi insist or to a part of the Wutai system, which was not intensely metamorphosed, just as in the case of the Jōsuiyo series of the Korean Wutai system along the lower reaches of the Yalu River.

PRECAMBRIAN GRANITES IN KOREA

More difficult and important problems are found in the chronological interpretation of the Precambrian granites in Korea.

S. Nakamura proposed the term Kokulian granite for the pre-Sinian granites in Korea, except the Seikoshin gneiss in Hamhŭng district, South Hamgyŏng-do, which is clearly later than the Kokulian in origin. The granite under consideration is characteristic in having gray to dark gray feldspars, with large crystals of grayish microcline sporadically scattered in the rock, and in often having garnet, cordierite, graphite, or tourmaline as important accessories; its quartz is commonly gray, sometimes rose, and rarely tinged with violet.

That the mica-schists are quite different in age from the Jurassic beds is suggested by the observations at Munsan about 25 km southwest of the Chongok district. At Munsan there are similar Jurassic beds containing plant fossils, with a marked basal conglomerate, and the beds rest with profound clino-unconformity upon a complex of mica-schists apparently similar to those in the Chongok district. Is there no room for doubt about the occurrence of the fossil bed reported by Yamaguchi?

Another point which needs attention is that there is no possibility to assign the Rensen system to an age younger than the fossil bed reported by Yamaguchi or the Kyūzan formation intercalating the fossil bed. The major portion of the Rensen system is intimately intruded by the so-called gray granite gneiss, and gneisses quite similar to it are discordantly covered by the lower Paleozoic Chōsen system or the upper Proterozoic Sinian system in various places of Korea. Yamaguchi did not state in his paper that the gray granite gneiss or the portions of the Rensen system invaded by gneisses are younger than the fossil bed.

However, it is not impossible that a part of the Rensen system, which, according to Yamaguchi, rests upon the Kyūzan formation with the fossil bed in question, is younger than the latter, or that strata quite different in age, for instance the Jurassic beds cited above, are commingled with the crystalline schists of the Rensen system.

[7] At the time of translation the author revised his original manuscript, so references do not completely coincide with those in the original.

The rock generally contains many accidental xenoliths, mostly of sedimentary origin, and exhibits a more or less distinct banded flow structure.

Granites with these characteristics, as stated above, are discordantly covered by lower Cambrian beds of the Chōsen system in various places in Korea, and have been well known among Korean geologists under the name of "gray granite gneiss", the typical granite being the Kankō gneiss of the writer (Tateiwn, no date, Geol Atlas Chōsen no. 6) in the Hamhŭng district, South Hamgyŏng-do.

The Kokurian granite has been correlated to the Kungchangling granite of South Manchuria or to the Taishan granite of North China. But, it is highly probable that granites quite different in age are imprudently grouped together under the term Kokulian granite. The author is of the opinion that the granite should be classified into at least two large groups, namely, the younger intruded the Wutai system and the older intruded the Rensen system, but may be discordantly covered by the Wutai, although the chronological as well as stratigraphical relationship between these two groups has not actually been verified.

Some examples from Korea of Precambrian granites which may belong to the younger group, as defined above, are the tourmaline granite and the schistose granite of P'ungsan-gun, South Hamgyŏng-do, described by Y. Kinosaki (1938), and the red granite by S. Kawasaki (1916), including the Koho granite, the Ryuyori granite, and the Meisen schistose granite, all by Y. Kinosaki (1932), together with the schistose granite of the Ch'ilbo-san district reported by the author (Tateiwa, I., 1925). All of these examples were found within, or adjacent to, the extensive terrain of the Matenrei system, piercing the latter or inclosing xenoliths of crystalline schists which are more or less similar in lithological nature to the Matenrei system.

Of the granites enumerated above, the former two by Y. Kinosaki do not differ in essential nature from the Kankō gneiss in Hamhŭng district, which may also belong to the same category as the others. The remaining ones differ by having reddish instead of gray to dark gray feldspars.

In addition to the above, another example can be added to the same category, that is the Ritsura granite by S. Matsushita (1943) in the central part of Hwanghae-do, which is covered by the Grabau's Sinian system and is closely associated with older schistose rocks.

Next, examples of the older group of granites are found among the granites which intruded the Rensen system. The granitic rocks intricately intruding the Rensen system may represent the older group in Korea. In the scope of my study, however, the granite presumably of the older group cannot be distinguished in lithological character from the gray granite gneiss of the younger group. The areal extension of the older granites, therefore, has remained quite uncertain.

In Korea, there is one more example that suggests Precambrian igneous activity. That is the nepheline syenite of P'yonggang district in the northern part of Kangwŏn-do.

The extensive terrain extending from Kŭmch'ŏn district of Hwanghae-do easterly to Kŭmhwa district, Kangwŏn-do, throughout P'yŏnggang district, is occupied largely by thick beds consisting mainly of mica-schists, phyllite, limestone, and dolomite, with intercalating manganese beds. Those beds lack fossils and probably belong to the Sinian system as previously designated by S. Nakamura. The strata are undoubtedly intruded by masses and dikes of the nepheline syenite with more or less distinct gneissic structure; no examples with the gneissic structure seen in the nepheline syenite are known among the rocks intruding the Paleozoic or later strata within Korea. In short, if the thick beds truly belong to the Sinian, as is highly probable, the author does not hesitate to report the Precambrian age of the nepheline syenite to be younger than any of the granites enumerated above. However, so far as the stratigraphic hiatus in the upper part of Grabau's Sinian system is taken into consideration, the chronological interpretation of the syenite may not be settled, because, in the limit of present knowledge, it seems quite uncertain that the uppermost portion of the thick beds is also invaded by the syenite. In this paper the author has tentatively followed the stratigraphic interpretation by S. Matsushita and considered the syenite to be of an age corresponding to the interval in the upper part of the Sinian system, viz., between the Kuken and Shidōgu series.

In gneissic structure, the syenite is comparable to the Seikoshin gneiss, which is clearly younger than the gray granite gneiss in the Hamhŭng district, as mentioned previously. That Grabau's Sinian system in Korea is either free or not free from intrusion by Precambrian grainites has remained uncertain.

Precambrian granites, reported from South Manchuria and North China, are known as the Kungchangling and Tuimenshan granites in South Manchuria, and the Taoko and Taishan granites, besides the "oldest gneissose rocks", in North China. At present there seems to be almost no room for doubt concerning the later origin of the Kungchangling and Taoko granites in comparison with the Tuimenshan and Taishan granites.

The Kungchangling granite was recently correlated with the Taishan granite by S. Matsushita (1952). R. Saito (1952), however, classified the granite into the younger or Hsienglushan granite and the older or Hsiaolikou granite, and correlated them with the Taoko and Taishan granite of North China, respectively.

A provisional conclusion on the chronological interpretation of these various granites in Korea, South Manchuria, and North China was inferred from this report and is shown in the following table.

TABLE 1

Upper Proterozoic	Sinian system in a narrow sense
	Nepheline syenite and Seikoshin gneiss of Korea; Kungchangling granite in part, namely Hsienglushan granite of S. Manchuria; Taoko granite of North China
	Huto system
Lower Proterozoic	Kokulian granite in part, Red granite and Ritsura granite of Korea; Kungchangling granite in part, namely Hsiaolikou granite of S. Manchuria; Taishan granite of North China
	Wutai system
Archean	Kokulian granite in part of Korea; Tuimenshan granite of South Manchuria; "Oldest gneissose rocks of North China"
	Rensen system

SYNOPSIS OF THE GEOLOGICAL SYSTEM OF KOREA
(Table 2, pages 1062-1070)

As was noted in the introduction, this report is based upon up-to-date knowledge from various sources and recently revised views of the author concerning the geology of Korea. The table may, therefore, reveal some advanced interpretation of the stratigraphy of Korea and, at the same time, various problems which cannot be settled at present and remain for future study.

In compiling the table, the author felt that it was necessary to unify the formational names which are common to Korea, South Manchuria and North China; he also set forth some examples of such unification. The scope of unification of formational names in these countries may be extended by future studies.

With regard to the phases of crustal movements in Korea, he briefly expressed his opinion concerning universal usage of terms such as the Himalayan and the Yenshanian movements, without proposing any new terms indigenous to Korea, except for a few subdivisional phases of the movement.

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TABLE 2. Synopsis of the geological system of Korea

Subdivision and geological age			Distribution, kind of dominant rocks, thickness	Mineral resources and miscellaneous remarks
Quaternary system		Alluvial series	Sand, gravel, clay, and peat forming alluvial plains and terraces; talus and fan deposits; some basaltic lavas of Cheju-do. Very extensive in distribution, but thin in thickness, generally 30 m or less, except the basaltic lavas.	Placers of gold, magnetite, illmenite, and some special heavy minerals dominated by monazite and zircon; quartz sand and ballstones (ballmills), etc.
		Often disconformity		
		Pleistocene series	Terrace deposits with mammalian fossils at Toaggwanjin, Chongsong-gun, N. Hamgyŏng-do, basaltic lavas and gravel beds on the Kaema plateau in S. and N. Hamgyŏng-do, Koksan-gun, Hwanghae-do, and Ch'olwon district, Kangwŏn-do; basalt flows on the Tertiary sediments in Changgi district, N. Kyŏngsang-do; trachyte flows on the coast of Myŏngch'ŏn district, N. Hamgyŏng-do, and Hamhung district, S. Hamgyong-do; shell beds of Cheju-do (Seikiho formation), etc.	Gold placers, diatomite and peat.
Unknown relationship				
Tertiary (?) system			Diatomite deposits of Anbyon, S. Hamgyŏng-do,[1] and Ch'olwon, Kangwŏn-do; lignite beds of Kowon-gun and Chongp'yong-gun, S. Hamgyŏng-do.	Diatomite and lignite.
		Unconformity?		
Tertiary	Upper	Schichihosan (Ch'ilbo-san) series Pliocene?	Alkaline liparites, alkaline trachyte, basalt, tuffs, gravel beds, etc., the majority of which belong to the Shichihosan group in N. Hamgyŏng-do and Toryusan group in S. Hamgyŏng-do. Alkaline volcanics of Paektu-san may also belong to the series.	Moonstone in the alkaline rocks as a semi-precious stone. The alkaline volcanics are highly variable in petrological nature, comenditic ones, however, being most common.
		Unconformity?		
		Ennichi (Yonil) series.[2] M. Miocene	P'chang district, N. Kyŏngsang-do. Upper: Shale and siltstone, rich in animal and plant remains. Lower: Dominantly conglomerate with sandstone and shale horizons. Thickness: 600 + m.	Fossils are especially abundant in the upper, dominant ones being marine molluscs and plants, the majority of the latter being more or less comparable to living species of the warm temperate zone of eastern Asia.

Tertiary		Epi-Chōkian interval stage of peneplanation	Clino-unconformity. Strata of the upper series are generally nearly horizontal or dipping at a very low angle and rarely faulted, while the middle and lower series are much disturbed by faults (mostly normal faults), warping, and insignificant foldings, the strata generally being tilted at angles of about 20° or less. In some places these sediments were accompanied by flows of basaltic and some other volcanic rocks. Clino-unconformity is clearly observable between the Schichihōzan and Meisen series in North Korea, and between the Ennichi and Chōki series in South Korea.		The main part of the crustal movement which disturbed the older series probably began in the Oligocene. It may represent the Nanling movement, a part of the Himalayan movement, in Korea. The Korean movement, however, seems to have a more intimate genetic relationship to the Oyashima movement of Japan, which is also a part of the Himalayan movement.
			N. Kyŏngsang-do	N. Hamgyŏng-do	
	MIDDLE	Chōki[3] (Changgi) series Miocene ↑ Oligocene	Bonkokuri (P'ŏmgŏng-ni) group: Andesite, liparite, parlite, tuff, conglomerate, sandstone, and shale, volcanic rocks being dominant. (Clino-unconformity) Chōki group: Conglomerate, sandstone, shale, various tuffs, coal diatomite, and interstratified basaltic flows; rich in plant remains, the flora being the Arctic Miocene type, somewhat modified; poor in animal remains which are represented by *Vicarya callosa* Jenkins and some other molluscan remains yielded from definite horizons. Thickness, except the basaltic flows, about 1, 400 m.	Meisen (Myŏngch'ŏn) group: Conglomerate, sandstone, shale, siltstone, coal, and interstratified basaltic flows; rich in animal and plant remains, the former being represented by forms of marine mollusks and the latter by a flora which consists largely of forms of Arctic Miocene flora mixed with those comparable to living species of a temperate zone. Thickness: about 1, 800 m.	Coal and diatomite The Chōki group strikingly covers the uneven surface of basement rocks of the Bukkokuji group, while the basement of the Ryūdō group referred to below is exceedingly flat. The flora of the Chōki series generally contains various forms of *Fagus*.
				(Unconformity) Ryudo (Yong-dong) group: Thick accumulation of basaltic lavas and basaltic tuffs, tuff breccia, and thin beds of sandstone. Upper: Shale, sandstone, conglomerate, and coal; rich in plant remains. (continued on next page)	Coal and clays ("Gairome" and "Kibushi") the coal being important in the north-eastern part of Korea.

TABLE 2. Synopsis of the geological system of Korea (Continued)

Subdivision and geological age			Distribution, kind of dominant rocks, thickness	Mineral resources and miscellaneous remarks
Tertiary	Middle		Lower: The fossil flora is of the Arctic Miocene type. Thickness of the upper: 600 m or less.	
(Unconformity?)				
Tertiary	Lower	Hozen (Pong-san) series Upper Eocene	Hwanghae-do Conglomerate, sandstone, shale and coal; rich in animal and plant remains, the former being represented by fresh water mollusks and some mammalian species, and the latter by flora of the Arctic Miocene type. The Tertiary beds constructing the Anju coalfield of S. P'yŏngan-do may belong to this series. Thickness: Over 350 m.	Coal of the Hozen series with that of the Anju coalfield are important in the coastal regions facing the Yellow Sea.
Epi-Bukkokujian interval Stage of widespread peneplanation (Peitai stage)			Unconformity The crustal movements are considered to have begun at the beginning of the Rakutō series and lasted in the block movements closely accompanied by widespread eruption of the comagmatic series of acidic rocks of the Bukkokuji group, the last phase of the movements being the Bukkokujian disturbance. The disturbance was preceded by two phases of regional or isolated local basins, the Rakutōan and Shiragian phases respectively. During the Shiragian phase an enormous amount of intermediate or rather basic lavas was poured out. The Bukkokujian phase was followed by a stage of peneplanation, the remnant of the peneplain being observable in very limited patterns on the Kaema plateau and on tops of high mountains in various places in Korea.	The phases of the crustal movements may represent the East Asiatic Yenshanian movement in Korea and its prolongation. The last phase, viz., the Bukkokujian disturbance, may be correlatable with the North American Laramide Revolution.
	Bukkokuji (Pulguk-sa) series		Bukkokuji group: N. and S. Kyŏngsang-do, N. and S. Cholla-do, N. Ch'ungch'ŏng-do, N. and S. P'yŏngan-do, etc. Granite, grano-diorite, diorite, liparite, feldspar porphyry, and various dike rocks; granite, liparite and feldspar porphyry prevail; liparite and feldspar porphyry are often dark grey, dark brown or dark green and are grouped under the name of black felsophyre. The granite piercing the Taisyu group may also belong to this group.	Various kinds of deposits of gold, tungsten, molybdenum, lead, zinc, copper, fluorite, alunite, etc. are found in close association with the intrusives of this group. The age of the Bukkokujian igneous activity being the most important metallo-genetic epoch in Korea.

Keisho (Kyong-sang) system Eocene ↑ L. Cretaceous or U. Jurassic	Eocene? ↑ Uppermost Cretaceous	(Intrusive contact) Taishu group: Tsushima (Japan), S. Cholla-do (?), S. Kyŏngsang-do (?), shale, mudstone, and sandstone, often with ripple marks and sun cracks; molluscan (mostly fresh water species) and plant re-remains (mostly dicotyledonous) are sparingly preserved. In Korea, it is often accompanied by tuffs. Thickness: over 600 meters in Tsushima.	The chronological relationship between the Bukkokuji and Taishu groups seems to be more intricate than is shown in this table. In other words, the two groups seem to be partly contemporaneous and stratigraphically inseparable.
	(Unconformity?) Shiragi (Silla) series U. Cretaceous	N. and S. Kyŏngsang-do, N. and S. Cholla-do, N. and S. Ch'ungch'-ŏng-do, Hwanghae-do, S. P'yŏngan-do, etc. Shale, mudstone, sandstone, conglomerate, tuff, tuff breccia, and andesite; of these, the first three are often reddish. Purplish, or greenish; ripple marks and sun cracks are very common; generally poor in fossils, but a rich dicotyledonous fossil flora was yielded from a black shale in the upper part of the series; animal remains are represented by non-marine mollusks and Estheria. Thickness, except andesitic flows, over 3, 000 m in N. Kyŏngsang-do.	The series has a thick bed of comglomerate at the base and thick accumulations of andesitic lavas, intercalated or constructing the top of the series. Various terms for the series in various districts in Korea have been suggested, for instance: Upper Daidō formation or Taihō system in the districts along the Taedong-gang, Chinan series in N. Cholla-do, and Eido series, excluding its lowest subdivision, in N. Ch'ung-ch'ŏng-do.
	Rakutō (Nak-tong) series U. Cretaceous ↑ L. Cretaceous, or U. Jurassic	N. and S. Kyŏngsang-do, N. Ch'ungch'ŏng-do, N. P'yŏngan-do. Shale, sandstone, conglomerate, and inferior anthracite, with a striking bed of basal conglomerate and shale and sandstone, often reddish. Except for the reddish beds, the series is rich in remains of non-marine mollusks and plant fossils; ripple marks are seen in places. Thickness: over 2, 550 m in N. Kyŏngsang-do.	The series is divided into two red and two blackish formations in alternation, with a blackish formation at the base, the lowest division being especially rich in fossils and corresponding to the Naktong (Rakutō) series, in a strict sense, by H. Yabe.
Epi-Daidōan interval	Angular unconformity	The strata of the Keishō system are generally tilted at low angles, less than 30°, or nearly horizontal, but show no marked folding, while the Daidō system is strongly disturbed by conspicuous foldings and reverse faults or overthrusts. The orogenic movements which disturbed the Daidō sediments were great and widespread, and preceded by a phase of subsiding movement of basins where the Daidō sediments were laid down.	The disturbance has been known under the name of Taihōan by E. Konno and may be chronologically correlatable with that of Ōga in Japan. It is interpreted as the first orogenic phase of the East Asiatic Yenshanian movement in Korea.
Daidō (Taedong) system M. Jurassic ↑ L. Jurassic	Daidō series	N. and S. Ch'ungch'ŏng-do, Kyŏnggi-do, Kangwŏn-do, Hwanghae-do, N. and S. P'yŏngan-do, S. Hamgyŏng-do. Shale, sandstone and conglomerate in alternation; sandstone and shale most prevailing; often with anthracite seams intercalated; rich in plant remains. Thickness: about 2, 650 m in S. Ch'ungcho'ŏng-do.	Anthracite seams are workable in places, but not important in Korea. The series in districts along the Taedong-gang has been called the Lower Daidō formation.

TABLE 2. Synopsis of the geological system of Korea (Continued)

Subdivision and geological age		Distribution, kind of dominant rocks, thickness	Mineral resources and miscellaneous remarks
Epi-Heian interval	Angular unconformity	The orogenic movement which resulted in this clino-unconformity is known by the name of Shorin disturbance. The disturbance does not seem to differ in any essential characteristics of the structure resulting from the Taihōan disturbance, but is far smaller in scale than the latter. However, it is noteworthy in the geological history of Korea has not been covered by any extensive marine water since this disturbance.	The disturbance is thought to have begun in a later stage of the Heian system. It may be chronologically correlatable with the Japan Akiyoshi disturbance.
Heian (P'yongan) system[4] Triassic ↑ M. Carboniferous	Green series Triassic	S. P'yŏngan-do, Kangwŏn-do, N. Ch'ungch'ŏng-do, N. Kyŏngsang-do and S. Hamgyŏng-do. Sandstone, shale, and conglomerate; sandstone, dark green to dark gray, rarely reddish, prevails; fossils are absent. The Red formation, well known by the name of Taishiin series in the P'yŏngyang coalfield, S. P'yŏngan-do, has been often correlated to the Green series, but the stratigraphic relationship between them is quite uncertain. The Red formation rarely contains silicified wood. Thickness: Over 1,000 m in S. P'yŏngan-do (over 1,700 m in the Taishiin series).	
	Kōbōsan (Kobangsan) series Triassic or U. Permian (or Permo-Triassic)	S. P'yŏngan-do, Kangwŏn-do, N. Ch'ungch'ŏng-do, N. Kyŏngsang-do and S. Hamgyŏng-do. Sandstone, shale, conglomerate, and anthracite; sandstone and shale prevail; rich fossil flora of a Mesozoic type has been yielded. Thickness: 350-500 m in S. P'yŏngan-do; 700 m in Kangwŏn-do	Anthracite
	Upper Jidō (Sa-dong) series L. Permian (Sakmarian)	S. P'yŏngan-do, Kangwŏn-do, N Ch'ungch'ŏng-do, N. Kyŏngsang-do and S. Hamgyŏng-do. Sandstone, shale, and anthracite; comparatively, sandstone prevails. The shale is generally carbonaceous and in cases strikingly aluminous; rich in plant and animal remains. Thickness: 30-100 m in S. P'yŏngan-do.	Anthracite of this series is very important in Korea. Aluminous shale is also important as a fire clay.
	Lower Jidō series L. Permian (Artin)	S. P'yŏngan-do, Kangwŏn-do, N. Ch'ungch'ŏng-do, N. Kyŏngsang-do, and S. Hamgyŏng-do. Shale, sandstone, hornstone, limestone, and anthracite; shale and sandstone are generally carbonaceous; rich in plant and animal remains. Thickness: 100-150 m in S. P'yŏngan-do.	Anthracite
	Epi-Kōten interval — Disconformity?	A disconformity is suggested paleontologically, but is not stratigraphically verified as yet.	

Koten (Hongjom) series M. Carboniferous (Muscovian)	S. P'yŏngan-do, Kangwŏn-do, N. Ch'ungch'ŏng-do, N. Kyŏngsang-do, and S. Hamgyong-do. Sandstone, shale, hornstone, conglomerate, limestone, and anthracite; comparatively, limestone prevails; sandstone and shale are often reddish; rich in animal remains but exceedingly poor in plant remains. Thickness: 250-300 m in S. P'yŏngan-do.	
Epi-Rakuron interval. Stage of widespread peneplanation (Rakuroan stage)	Disconformity The disconformity was long believed to be so great as to indicate the age of dry land ranging from the U. Ordovician to the L. Carboniferous. However, the existence of the Gotlandian limestone was suggested in 1934 from the derived fossils discovered in the basal conglomerate of the Jurassic Daidō series in Hwanghae-do, and then coralline fossils indicating the Devonian were unexpectedly discovered in a limestone block on the ground in Sunch'on-gun, S. P'yŏngan-do, although the limestones from which the above fossils were derived have not actually been disclosed as yet.	Doubtful fossils which, however, suggest the Gotlandian have recently been discovered in a thin bed consisting of arenaceous clay slate and limestone in Kumch'ŏn-gun, Hwanghae-do.
Chōsen (Choson) system, M. Ordovician – L. Cambrian; Great Limestone Series: Bantatsu (Mandal) series M. Ordovician	N. and S. P'yŏngan-do, Hwanghae-do, Kangwŏn-do, N. Kyŏngsang-do, and S. Hamgyŏng-do. Limestone, mostly massive; rich in animal remains, dominantly cephalopods and mollusks. The uppermost portion generally lacks fossils. Thickness: about 600 m in S. P'yŏngan-do.	Limestone is important as a raw material for cement manufacturing and some chemical industry in Korea. Paleontologically the series corresponds to T. Kobayashi's Toufangian series (Caradocian-Llandelian).
Chōsen (Choson) system; Great Limestone Series: Sozan (Ch'o-san) series L. Ordovician ↑ M. Cambrian	N. and S. P'yŏngan-do, Hwanghae-do, Kangwŏn-do, N. Kyŏngsang-do, and S. Hamgyŏng-do. Limestone, siliceous limestone, dolomite, shale, and clay slate, more or less impure limestone prevailing. The limestone is thinly bedded, often carbonaceous and variable in lithological characteristics, including oölitic, cryptozoon (Collenia?) and vermicular limestones; the base consists of a thin but persistent bed of black shale (Rinson shale) rich in Middle Cambrian fossils. In general, the series is fairly rich in remains of Crustacea and others. Marine algae is known as a representative plant remains. Thickness: 900 m in S. P'yŏngan-do.	Paleontologically the upper and middle parts of the series correspond to T. Kobayashi's Wolungian (Skiddavian) and Wanwanian (Tremadocian) series, respectively.
Yōtoku (Yangdok) series M. Cambrian ↑ L. Cambrian	N. and S. P'yŏngan-do, Kangwŏn-do, Hwanghae-do, N. Kyŏngsang-do, and S. Hamgyŏng-do. Sandstone, shale, clay slate, quartzite, and thin beds or lenses of limestone; shale prevails and is often sandy, rarely dark reddish; the base consists generally of quartzite, variable in thickness; shale, sandstone, and limestone lenses are often rich in remains of Crustacea and Brachiopoda. Thickness: 400 m in S. P'yŏngan-do; 550 m in Kangwŏn-do.	
(Disconformity or angular unconformity)		

TABLE 2. Synopsis of the geological system of Korea (Concluded)

Subdivision and geological age			Distribution, kind of dominant rocks, thickness	Mineral resources and miscellaneous remarks
Sinian system	Sinian system in strict sense	Kuken (Kuhyon) series	S. P'yŏngan-do, Hwanghae-do, Kangwŏn-do?, and S. Hamgyŏng-do? Clay slate, shale, phyllite, pebbly phyllite (tillite?), quartzite, and limestone, shale and phyllite dominating. Clay slate and slate often blackish. Collenia limestone is found in the basal horizon in some places. Thickness: 1,500 m in Hwanghae-do.	Insignificant iron formations in Kangdong district, S. P'yŏngan-do; marble, rosy or reddish orange in Sŏngch'ŏn district, S. P'yŏngan-do; manganese formations of Anhyop and Kumhwa districts, Kangwŏn-do
	(Unconformity?)			
	Sinian intrusive rocks		Nepheline syenite of P'yŏnggang district, Kangwŏn-do, and hornblende-biotite granite (Seikoshin gneiss) of Hamhŭng district, S. Hamgyŏng-do.	Sodalite in the syenite (subprecious stone)
(Intrusive contact? Disconformity or angular unconformity between the Kuken and Shidōgū series)				
Neo-Proterozoic	Huto system	Shidōgū (Sadangu) series	S. P'yŏngan-do, Hwanghae-do, Kangwŏn-do? and S. Hamgyŏng-do? Essentially limestone and dolomite with thin beds of clay slate intercalated; thin beds of Collenia limestone are found at the middle and uppermost horizons. Thickness: 2,000-2,400 m in Hwanghae-do; 1,500 m in S. P'yŏngan-do.	Marble
		Chokken (Chikhyon) series	S. P'yŏngan-do, Hwanghae-do, Kangwŏn-do? and S. Hamgyŏng-do? Clay slate, phyllite, mica-schist, quartzite, and limestone, with conspicuous beds of quartzite generally at base. Thickness: 3,100-3,800 m in Hwanghae-do; 700 m in S. P'yŏn-gan-do.	
Epi-Kokulian interval Stage of peneplanation?		Unconformity	The interval is suggested by observations in Songch'ŏn-gun and Sangwon district of Chunghwa-gun, S. P'yŏngan-do, where the Chokken series rests directly upon a complex consisting of mica-schists and gray granite gneiss.	
Early Proterozoic granites			A part of the Kokulian granite, or the gray granite gneiss: tourmaline granite and schistose granite of P'ungsan-gun in S. Hamgyŏng-do, and Kanko gneiss of Hamhung district in S. Hamgyŏng-do. A part of the Red granite: Ryūyōri granite of Tanch'ŏn-gun in S. Hamgyŏng-do, Meisen schistose granite of the northwestern part of Myongch'ŏn-gun, N. Hamgyŏng-do, and schistose granite of the Ch'iblbo-san district in Myongch'ŏn-gun, N. Hamgyŏng-do. Ritsura granite in the central part of Hwanghae-do.	Pegmatite dikes of Red granite often contain zircon and allanite, and dikes of gray granite gneiss in Yongch'on-gun, N. P'yŏngan-do contain large crystals of monazite.
Intrusive contact)				

Wutai system Early Proterozoic	Jōsuiyō (Sangsuryang) series[5]	Ch'angsŏng-gun, Sakchu-gun, and Uiju-gun, N. P'yŏngan-do. Sandstone, hornfels, clay slate, mica-schist, epidote schist, limestone, dolomite, and quartzite; base unknown. Thickness: over 4, 800 m in Uiju-gun.	Crystalline graphite and sillimanite.
	(Unknown relationship. Almost contemporaneous?)		
	Yokusen (Okch'on) system[6]	N. and S. Ch'ungch'ŏng-do and N. Cholla-do. Upper: Sandstone, hornfels, phyllite, mica-schist, conglomerate, quartzite, hornblendite, limestone, and iron formations. Of these, phyllite is most common. A thick bed of phyllite contains sparingly angular or subangular pebbles of quartzose rocks and seems comparable to tillite. Middle: Amphibole schist, limestone, mica-schists, phyllite, and hornfels, limestone and amphibole schist being dominant comparatively. Lower: Sandstone, hornfels, metamorphosed clay slate, and quartzite; the metamorphosed clay slate is often accompanied by deposits of earthy graphite. The base is not known. Thickness: Very thick.	Earthy graphite and iron.
	(Unknown relationship. Almost contemporaneous?)		
	Matenrei (Mach'ollyong) system[7]	N. and S. Hamgyŏng-do Upper: Mica-schist, limestone, dolomite, and various gneisses, the mica-schist being dominant. Middle: Limestone, dolomite, magnesite, and mica-schist, limestone and dolomite prevail; a <u>Collenia</u> limestone is found intercalated in a middle horizon. Lower: Mica-schist, graphite schist, quartzite, and dolomite, the mica-schist prevails; base unknown. Thickness: over 9, 100 m.	Magnesite deposits, very large in scale; crystalline graphite; apatite. The large scale iron formation of Musan, N. Hamgyŏng-do is thought to be of the system, but is quite uncertain.
Epi-Archean interval		The interval has not been actually verified.	
Archean granites		A part of the Kokulian granite in the terrain of the Rensen system.	
(Intrusive contact)			
Rensen (Yonch'ŏn) system Archean		Kyonggi-do, S. Ch'ungch'ŏng-do, and Kangwŏn-do. Upper: Mica-schist, phyllite, and micaceous hornfels. Lower: Mica-schist, amphibole schist, hornblende pyroxene hornfels, quartzite, and siliceous limestone, together with iron formations. Base unknown. Very thick.	Iron and cyanite.

FOOTNOTES TO PRECEDING TABLE

[1] According to B. V. Skvortzov, the diatom remains of Anbyŏn suggest the Upper Pliocene.

[2] The boulder deposits (Shinkō formation) unconformable resting upon the Chōki series (Chōhōri formation) in Sinhung district, S. Hamgyŏng-do, probably belong to the Ennichi series and may represent its earlier stage.

[3] Major part of the Tertiary formations along the Tuman-gang, N. Hamgyŏng-do are divided by a distinct unconformity into the Yūsen (Yuson) and Koei (Haengyŏng) formations, which may be presumably correlated to the Ryūdo and Meisen groups respectively. Formations which may belong to the Choki series commonly have coal seams and are found in the Sinhung district (Chōhōri formation) of S. Hamgyŏng-do, Tonch'ŏn district in the northern part of Kangwŏn-do, and Samch'ŏk district in the southern part of Kangwŏn-do.

[4] The Heian system in Korea corresponds to the South Manchurian type of upper Paleozoic system of Manchuria. Another type of Manchurian upper Paleozoics, the North Manchurian type, is represented in Korea by a thick series of shale and sandstone in the Tuman-gang river basin which is considered to be an extension of the Tuman formation, one of the North Manchurian upper Paleozoic series.

[5] Originally crystalline schists in the Ch'angsŏng and Sakchu districts were included in the series by S. Nakamura (Mineral Resources of Chōsen, v. 1, 1915). In comparison, crystalline schists of the Uiju district (E. Takhashi, Uiju sheet, scale 1:200, 000, 1940) are not so intensely metamorphosed, but are considered to be of a continuous terrain of crystalline schists extending from the adjacent district (Ch'angsŏng and Sakchu districts).

[6] Various metamorphosed sedimentaries comprise the Yokusen system and occupy an extensive northeasterly trending belt passing through Okch'ŏn district in South Korea. The system partly belongs to the Heian system, as pointed out by N. Kobatake (Kobatake, N: Considerations on the Yokusen system, Sci. Rep. S. Branch School, Osaka Univ., no. 1, 1952), and part of it can hardly be differentiated from some parts of the Cretaceous Shiragi series, which suffered much metamorphism by contact action of granite that invaded the series (Shimamura, S., Geol. Atlas of Chōsen, no. 5, 1925). However, it is already well known from the study by S. Nakamura that the complex, in part, is intruded by gray granite gneiss, probably Precambrian (Mineral resources of Korea, v. 8, 1925). The parts which certainly belong to the Heian system or Shiragi series, or to any series other than the Yokusen system, are of course to be excluded from the system in question. But, it is improbable that the complex which has been known as the Yokusen system belongs entirely to the Heian system, although the probability of it was recently discussed by Kobatake (Kobatake, 1952, Op. cit.). The Yokusen system in the present table is tentatively interpreted on the basis of old criteria by S. Nakmura.

[7] Whether strata of the Chōsen system are unconsciously commingled with those of the Matenrei or not, as S. Nakamura once discussed with me, remains unsettled for future study.

ON SOME ACHIEVEMENTS OF GEOLOGICAL SURVEYING AND PROSPECTING IN THE CHINESE PEOPLE'S REPUBLIC[1]

by

P. Ya. Antropov[2]

• prepared by the U.S. Joint Publications Research Service •

ABSTRACT

Oil and gas prospecting in China has located promising shows in Tertiary deposits of the Ts'aidam valley of southern China, the Kansu corridor, the Chungar trough of northwest China, and in Mesozoic deposits of the Turfang valley in Sikang.

The iron content of Precambrian quartzite ores in northern China averages 47 percent in 1957, 19 million tons of iron ore were mined in China. Reports on recent product and prospects for future development are included for manganese, tin, tungsten, copper, bauxite, mercury, antimony, molybdenum, nickel, cobalt, chromites, titanium, vanadium, gold, rare earths, uranium, boron, phosphorites, apatites, quartz, diamond, and asbestos. --M. Russell.

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A group of Soviet geologists made up of P. Ya. Antropov (head of the delegation) K. I. Satpayev, Kh. M. Abdullayev, N. P. Budnikov, N. A. Bykhover, G. N. Zaytsev, N. V. Petrovskaya, and A. A. Yamnova was awarded the honor of participating in the work of the First All-Chinese Conference on Geology and Useful Minerals (Peking, September 1958). The conference carried out its work against the background of an unprecedented technical and cultural revolution, the grandiose development of all branches of the national economy, and a tremendous tide of creative activity of the great masses of the Chinese workers.

Even quite recently, prior to the creation of the People's Republic, China was an economically backward semi-colonial country, depending on foreign imperialism, in which the vestiges of feudal relationships dominated. The industry produced only approximately 10 percent of the national economic product, and 90 percent of the production was produced by agriculture and by hand work enterprises. The level of the industrial production was extremely low. In 1942 China produced only 2 percent of the world's production of cast iron and 0. 6 percent of steel. Machine building was in the initial stages. The principal portion of the industrial enterprises was in the hands of foreign capital.

As a result of the adoption of the general line of communist party of China and of the successful fulfillment of the first five year plan in People's China, the problem of socialist transformation was solved in agriculture and industry, and private ownership of the means of production was essentially liquidated; the social sector occupies a strong dominating position in the economy of the country. In 1957, compared with 1952, the gross production of the industry increased by 141 percent, including the production of the means of production, which increased by 3. 2 times. The melting of steel in 1957 reached 5, 350 thousands of tons, the production of coal 130, 730 thousands of tons, that of petroleum 1, 460 thousands of tons; the production of electricity was 19. 3 billions of kilowatt hours; the production of cement is 6, 860 thousands of tons, that of chemical fertilizer -- 800 thousand tons, cotton cloth -- 5 billion meters, and the grain crop was 370 billion dzins.

In 1958 there was realized a large scale rise in the economy and culture. By the end of the year one expects an improvement, compared with 1957, in the volume of the gross production of the industry and agriculture, by not less than five percent.

Great success has been attained during the years of the first five year plan in the development of the mineral-raw material base of China, the territory of which differs in having a great variety of geological conditions, that are favorable for the extraction of various useful minerals. The communist party and the people's government of China have created a geological service for the country, have trained thousands of geologists, geophysicists, hydrogeologists, and drillers, have constructed plants for the manufacture of geological-prospecting equipment and outfitting, have organized great searches and prospecting for deposits of mineral raw material. Chinese geologists have uncovered and prospected for hundreds of new deposits of useful minerals, necessary for the development of the national economy of the republic. Particularly great success has been attained in the increase of the prospected reserves of coal, iron ore, tin, molybdenum, tungsten, copper, lead, zinc, and piezooptical

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[1] Translated from Sovetskaya geologiya, no. 12, 1958, p. 3-12. JPRS:L-1008-N.

[2] Ministry of Geology and Conservation, U.S.S.R.

raw material. At the present time the Chinese People's Republic occupies a leading position in the world in its reserves of tin, tungsten, molybdenum, antimony, iron ore, coal, and phosphate raw material.

During recent years reliable geological bases have been established for uncovering industrial deposits of chromites, nickel, gold, beryllium, tantalum, niobium, rare earths, borates, asbestos, and other types of mineral raw material, which until recently were considered in short supply in China. The general reserves of coal inside the ground of the Chinese People's Republic is estimated to be 1, 500 billions of tons, and the prospected reserves of categories $A + B + C_1$ amount to 43. 6 billions of tons. The production of coal in China has grown from 1949 to 1957 by more than four times (from 31 million to 130 million tons). During the current year the total increase in capacity of the mines and carriers, which is to be organized, amounts to 120 millions of tons; the extraction of coal will reach not less than 210 millions of tons.

The principal problems of the technical revolution in the coal industry is the hydromechanization of underground extraction. By the end of 1958 hundreds of sections and tens of mines will be hydromechanized.

Among the prospected coal deposits of the Chinese People's Republic, a great fraction is that of high grade coal, of which a great quantity is of the coking type. Coal deposits in China are characterized by relatively small thickness of productive layers, but have a high working coefficient of coal content. First place in the reserves of coal is occupied by northern China, where the large Datun coal basin is located with a total reserve of coal of more than 40 billion tons. The coal deposits here belong to the Permian-Carboniferous and Jurassic deposits. Great reserves of coking coals of northern China are concentrated in the deposit of Kailang, Feng-Feng (Hopeh Province), Luan (Shensi Province), and others. It is planned to increase the production in the Kailang deposit in 1958 to 11 million tons.

Second place in reserves and first place in extraction of coal belongs to the northeast of China, where there are many large coal deposits: Hekang, Fushun, Fuhsin, Penhsi, Maashan, Hsian, Tunghua Peip'iao, Yentai, and others. In Hekang coal basin, from the Jurassic period, there is coking coal with a total reserve of 5 billion tons. The Fushun basin extends over 16 km, has a width of 4 km, and in addition to Tertiary coal (reserves approximately 1 billion tons) contains oil shales (200 million tons). The reserves of Jurassic coal of the Fuhsin basin are estimated at 4 billion tons, that of Maashan at approximately 1 billion tons, that of Peip'iao on the order of 200 million tons. The deposits of K'enshi and Yentai of Carboniferous age have reserves of 380 and 40 million tons respectively.

The foregoing deposits serve as the basis of the coal base for the metallurgical plants of the northeast China (Anshan and Penshi combines). The extraction of coking coals exceeds 5 million tons here, and the annual extraction of coal at the Fushun and Fuhsin deposits amounts to more than 20 million tons. In 1958 it is planned to extract in Fuhsin 12 million tons of coal, and in Fushun 11 million tons.

In inner Mongolia the greatest deposit is Tsuchishan with total reserves of coking coals of nine billion tons. Coking coals are contained also in the deposit of Shukueichi. Also contained here is a large deposit of brown coal -- Chialainor, with reserves of more than 3 billion tons.

In the northwest China, the largest deposits are in Weipei with the total reserves of more than 9 billion tons. Coking coals are known to be located in the deposits of Pinglo and Tungkuang.

In central China there is a large deposit of coking coal -- Pingtishan -- with a total reserve of more than 70 billion tons. Small deposits of coal are located in other regions of the Chinese People's Republic. There is no doubt that Chinese geologists will uncover more.

In the Chinese People's Republic, the total reserves of combustible shales are estimated to 18. 2 billion tons, which when converted into shale tar is equivalent to approximately 700 millions of tons of petroleum. The prospected reserves of shales amount to 6. 9 billion tons. The largest deposit of oil shales are located in northwest and northeast China, in the regions of Fushun Maoming, and in the districts of Feng and Yungshou (Province Shensi).

When processed, shales produce up to 12 percent of petroleum. At the present time there are in the Chinese People's Republic five shale-distilling plants and two plants for production of synthetic liquid fuel based on coal. The principal amount of shale tar is produced in the first and second Fushun shale processing plants. In order to expand the production of synthetic liquid fuel, two shale producing plants will be built, in Fushun and Maoming, constructed with the aid of the Soviet Union.

The ideas of bourgeois scientists predominated, mostly of British and American geologists, that China is very poor in petroleum or has hardly any. In spite of these ideas, there were organized in people's China extensive geological and prospecting projects concerning oil and gas. These projects are being developed particularly intensely during the recent time, within the framework of the "big jump." In the ter-

ritory of China there are in operation at the present time 11 large petroleum drilling expeditions, comprising more than 200 search parties, equipped with necessary modern drilling and geophysical equipment and apparatus. In addition for searching expeditions and parties, in many petroleum and gas bearing regions of the country there have been created geological-prospecting administrations and divisions, which carry out prospecting and basic drilling for oil and gas. With each year there is a sharp increase in the volume of deep drilling. During the current year the Ministry of Petroleum Industry of the Chinese People's Republic will drill approximately 1, 200, 000 meters, which exceeds considerably the volume of drilling carried out during the entire first five year plan.

As the result of these operations, great success has been attained in uncovering the prospects of oil and gas production in the country, in discovery of oil and gas deposits. At the present time the total area of grounds that offer promise with respect to oil and gas bearing, are estimated to be 2, 700, 000 square kilometers (almost one-third of the entire territory of China). The greatest promise is offered by the valleys and troughs between the mountains: Szechwan, Chungar, Ts'aidam, and Tiuchuan -- on the territory of which reinforced search and prospecting work is being carried out in recent times. During the last three there has been disclosed in the prospecting regions of China more than 600 structures that are favorable for the establishment of search-prospecting operations for oil and gas, and more than 1, 000 oil and gas strikes have been established. The most important result of the geological-search and prospecting operations during the recent years is the discovery of a series of oil and gas-bearing regions and deposits in the country, having, in all probability, very rich reserves of oil and gas.

Deserving of particular attention are the results of the search and prospecting work in the Szechwan trough, located in the southwest portion of China. In this trough, with an area of approximately 190, 000 square kilometers, there are mostly Mesozoic deposits -- of the Jurassic and Cretaceous periods. In the central portion of the trough there have been established 22 large anticlinal structures of the "platform type" with limbs dipping away at from 2-3° to 6-7°. The areas of the individual structures range from 50 to 500 square kilometers and more. The object of the prospecting are Jurassic and Triassic deposits, and the principal object is the lower portion of the upper Jurassic, represented by continental deposits. The collectors of the oil are dense sandstones, having low porosity and permeability possibly cracked.

The first oil well was obtained here at the end of 1956 at the structure of Liunyuhsi, with dimensions of more than 500 square kilometers. At the present time, the industrial value of five large structures has been established, with a total area of approximately 1, 000 square kilometers. Numerous wells, drilled in these structures produced gushers with yields, for a 7 mm [cm?] pipe, of 30-80 tons a day, and well No. 4 on the Nants'un structure gave approximately 200 tons a day during test. The deposits of oil are ascribed to one stratigraphic horizon and are at a relatively shallow depth, on the order of 1, 100-1, 600 meters. On many other structures prospecting work, is being done and there is no doubt that in the near future there will be discovered in this region new petroleum deposits.

In the southern part of the Szechwan trough there are known more than 60 structures, on ten of which there already has been established the presence of commercial gas (essentially from Triassic deposits). The total resources of gas are estimated to be tens of billions of cubic meters. Searching and prospecting work are carried out also in the eastern and western portion of the Szechwan trough, where there have been established many structures in Mesozoic deposits. Recently in the eastern part of Szechwan, on the Hsiangohsi structure from the lower portion of the upper Jurassic, an oil gusher was obtained, and in certain other structures prospecting wells have uncovered oil-bearing sands. It is assumed that the eastern part of the trough will be analogous as far as prospects of oil and gas deposits to the central portion. The Szechwan trough is being quite justifiably considered by our Chinese friends as the principal oil and gas region of the country. During the current year it is planned to drill here prospecting wells with a total length of approximately 400, 000 meters.

The geographic and economic position of the Szechwan province produced favorable conditions for the rapid development of petroleum and gas industry in this region.

Important results of search and prospecting work have been obtained in recent years in the Chungar trough, located in the northwest China, which has expanded considerably the prospects of the development of petroleum industry in this region. In addition to the known deposits of Tushangtse and Karamai, there were uncovered here in 1958 the new petroleum and oil deposits. Of particularly important significance is the discovery of an oil deposit in Werhe, located 100 kilometers to the east of Karamai. In connection with this it was established that the great region between Karamai and Werhe is promising from the commercial point of view. In addition, prospecting work has extended considerably the area of the Karamai deposit in the southern direction.

The great upsurge in geological searching and prospecting operations has made it possible

to make considerable progress in the discovery of new oil and gas deposits in the Ts'aidam valley. In this valley, located in the southern part of China, over an area of approximately 120,000 square kilometers there are developed mostly Tertiary deposits, with a total thickness of more than 6,000 meters. There are known here 105 structures, many of these have been surveyed. Up to the present time more than 200 wells in the Ts'aidam valley have given oil or gas. The most promising are the structures located in the western and northwestern portion of the valley. Recently in many structures there have been obtained here oil gushers with yields of more than 100 tons a day. The productive horizons are attributed to the lower portion of the Tertiary section and lie at low depths (300-600 meters). In the northern part of the valley, in many structures there have been established deposits of commercial gas. Prospecting work is continued now in the Ts'aidam valley on more than 35 structures, located at various portions of the valley.

In 1957-1958 there were discovered, in the western portion of the Tiuch'uang valley (the "Kansu corridor"), where known deposits Laochunmiao and Shayukou are located, new oil deposits (Yarhsia and Pianghe). In the Yarhsia deposit, with a depth on the order of 2,300-2,700 meters, there are obtained from Tertiary deposits gushers of oil with yields from 30 to 1,000 tons per day. In 1958 it is proposed to extract 100,000 tons of oil.

Prospecting work for oil is being developed also in the Turfang valley in Sikang, where it is proposed to put ten areas in deep prospecting. Of great interest are the results of the search and prospecting work carried out over the extensive plain of Sunghao, in north China. Here there are Mesozoic deposits of thickness more than 400 meters. At the present time there are known in this plain ten structures, of which four are being prospected. In this year in one of the structures, with an area of approximately 1,000 square kilometers, located northwest of the city Sanchun, in a prospecting well (at depths from 500 to 900 meters) in Cretaceous deposits, there have been discovered 22 oil-bearing horizons, with a total thickness of 66 meters. Oil-bearing sands have been discovered also when drilling wells in many other points of the plain, this being evidence of the promises afforded by the northern regions of China with respect to oil.

Geological surveying and prospecting for oil and gas are carried out at the present time also in many other regions of China: on the Ordos platform, in the north China plain, in the provinces of southwest China, etc., where many interesting data have also been obtained, evidencing prospects of oil being found in the country.

Thus, at the present time there is no doubt that China has very rich deposits of oil and gas. The previously dominating statements of the bourgeois scientists concerning the oil poverty of China turned out to be theoretically inconsistent and have been brilliantly refuted by practice. It is clear that such statements on the part of the American and British scientists were necessary to the foreign capitalists in order to disinterest the geological service of China and thereby tie it closer to the imperialistic chariot, thus retarding the industrial development of the country. Thus undoubtedly they succeeded with the bought Kuomintang regime, but was fully and finally liquidated in out time.

In connection with the problem posed and resolved by the Chinese geologists of the disclosure of the oil and gas bearing regions, it is appropriate to note that Mesozoic-Cenozoic deposits and in particular the deposits of the Cretaceous system, appear to be oil and gas bearing in many parts of the earth. We mention this to help our Chinese friends to make more rapidly practical conclusions in their searches for oil and gas in the western regions of China, which bound with the territory of the U. S. S. R.

The geological reserves of the iron ore in the Chinese People's Republic are estimated to be 100 billion tons, and the prospected reserves amount to 6 billion tons.

The greatest resources of iron ore are concentrated in northeastern China, where these ores are represented essentially by iron quartzite, of proterozoic age, and having a relatively low content of iron.

In northern China there are mostly developed deposits of iron of the sedimentary type, connected with the Precambrian periods. The ores are represented by hematite variants of oölitic structure. The iron content in them averages 47 percent. A very interesting deposit was recently discovered in inner Mongolia. Here the hematite-magnetite ores of the contact-metamorphic type, contain in addition to iron considerable amounts of rare earths and fluorite. In south central China there are many deposits of hematite and magnetite ores of the contact type with an iron content of 45-60 percent. Numerous iron-ore deposits, mostly small ones, are known in west and east China.

The extraction of iron ore in the Chinese People's Republic amounted to 19 million tons in 1957, i.e., almost five times greater than in 1952. In the western portion of the Hupeh province there was in 1957 the very large west-Hupeh iron-ore basin, with an area of several thousands of square kilometers. Here are located iron ores of the sedimentary origin. Reserves of the basin are one billion tons. In the Kwangtung Province there was disclosed a new

zone of ore with an extent of up to 28 kilometers with a width of the ore outcrops of 15-20 meters.

New deposits of iron have been uncovered in recent years in the provinces of Kansu and Ts'inhai.

Obviously, a portion of the prospected reserves of iron ore require enrichment during the process of their development in use for blast furnace manufacture, which makes it possible to increase the contents of the metal in the ore and get rid of harmful impurities.

In the future, Chinese geologists are faced with the problem of not only attaining a further increase in the reserve of iron ore, but also to prospecting for new deposits, rich in iron ore. When we were in China, we recommended to our friends that they pay particular attention to the regions where erosion crusts can develop, which may be connected with rich deposits of iron and nickel ores (similar to the deposits uncovered in the U. S. S. R.).

In connection with the call of the Chinese communist party for increasing the manufacture of steel in 1958 to 10, 700, 000 of tons in various regions of the country there have been constructed a large number of small blast furnaces, for which the source of raw materials are as a rule local small iron-ore and coal deposits. Seventeen hundred small Bessemer converters and hundreds of small rolling mills have been put into operation.

Relatively widely located in China are deposits of manganese, which belong mostly to the sedimentary type. A greater portion of these deposits are characterized by ores with a content of manganese of 18-22 percent and higher. The extraction of manganese has increased from 22, 000 tons in 1948 to 540, 000 tons in 1957.

China occupies first place in the world in reserves of tin and one of the first places in reserves of tungsten and molybdenum. Two hundred and ten deposits are known in this territory.

The largest primary and placer deposits of tin are located in the provinces of Yunnan, Kwangsi and Kwangtung. The first place with respect to reserves and extraction of tin is occupied by the Yunnan province. Here the primary deposits are ascribed to limestones of the Sinian formation and to their contact with granite intrusions. The ore bodies have a tubular form. They come in a great variety of thickness. In the deposits there are found, in addition to tin, also commercial concentrations of copper, lead, zinc, and molybdenum.

In the Kwangsi province, cassiterite-tungsten ores of the stockwork type are ascribed to granite intrusions, which break up the limestones, sandstones, and shales of the middle Paleozoic. The original deposits of tungsten belong to two genetic types: skarn -- with scheelite, and vein -- with wolframite. A great role in the extraction is played by placer deposits of tungsten. The tungsten of the primary and placer deposits is usually accompanied by bismuth, which is also extracted from these deposits.

The greatest deposits of molybdenum are located in the provinces of Liaoning, Shensi, and Kirin. They are represented by vein-like intruded ores, usually belonging to granitoids or skarns along the contact with granite. Ore deposits are distinguished for large size, which can be traced to depths of 500-600 meters and are characterized by a relatively low content of the metal. In central and south China there are many known points of molybdenum ores, usually connected with vein tungsten deposits.

China occupies first place in the world in reserves of antimony, and one of the first places in its extraction. The principal deposits are located in the provinces of Hunan, Kweichow, Kwangsi, Kwangtung, and Yunnan, where three parallel ore zones extend from east to west. Two types of deposits are observed: antimony-mercury which represent hydrothermal filling of the cracks, and antimony-lead replacement deposits in limestones. Belonging to the first type is the principal mass of deposits of the Chinese People's Republic. The greatest resources of antimony are concentrated in deposits of the province of Yunnan. Here the deposits of antimony are connected with the zones of large fractures in the Devonian quartzite sandstones and limestones, and are represented by veins and stockworks. The average contents of antimony in the ores fluctuates from 1. 9 to 25 percent.

Numerous mercury and antimony-mercury deposits are known in many regions of the country. The most substantial of these are located mostly on the boundary of the Kweichow province and Hunan province. The deposits of vein type belong to the brecciated zones of limestones and shales of the Paleozoic period. The average contents of cinnabar in them fluctuates from 1 to 4. 5 percent.

An extensive appearance of copper ores was observed in many regions of China. In recent times there have been discovered in the Chinese People's Republic many new commercial deposits of copper, which, judging from preliminary data, have considerable resources. The contents of copper in individual deposits reaches 1. 7 percent. A considerable portion of the prospected resources is concentrated in the southwest regions, where the largest deposit is in carbonate rocks.

Polymetallic deposits of China represent principally replacement bodies in limestones or veins in limestones, shales, sandstones, and quartzite near granite intrusions. Many deposits contain considerable amounts of silver, up to 300-600 grams per ton of ore. The largest deposits of lead and zinc are concentrated in southwest China.

Numerous reported deposits and ores of bauxite have still not been adequately prospected, but there are grounds for hoping that the deposits will be quite considerable.

In addition to bauxites, there are known deposits of alunites and alumina-shales in China. The latter extend particularly extensively and belong to Permian-Carboniferous deposits, to Permian, and Permian-Triassic deposits. The contents of alumina ranges from 35 to 72 percent, that of silica from 10 to 40 percent.

Prior to the liberation of China it was assumed that the country contained practically no large masses of basic and ultra-basic rocks, and therefore the prospects of finding deposits of nickel were small. Now this point of view has been refuted, and in many regions there was established not only widespread presence of basic and ultra-basic rocks, but sulfides and silicates of nickel have also been discovered. In inner Mongolia, in the province of Yunnan, there have been discovered recently deposits of nickel silicate, belonging to the ancient erosion surface, and this is of great significance. It is the duty of our Chinese friends to prospect these rapidly and to place them in the service of industry.

Cobalt usually appears together with deposits of nickel. It is also frequently present in ores of iron or forms independent deposits, in which the average content of the cobalt is very good and amounts to 0.3-0.8 percent.

Chromites and titanium still await a study; titanium deposits proper have not yet been discovered by our Chinese friends, but great reserves of titanium and vanadium are included in titanium-magnetite deposits of Dayamo and Heshan. Chinese geologists quite recently discovered many deposits of chromites in inner Mongolia, but these have not yet been investigated.

Gold deposits are known in almost all the provinces of Chinese territory, but very little has been done about their prospecting; as is known, the extraction of gold in Kuomingtang has been negligible. The principal portion of the extraction was in the provinces of northeast China, where there are both primary and placer deposits.

In recent years, in many regions of China, there have been disclosed many very interesting deposits, of practical significance to science, of rare metals: beryllium, lithium, tantalum, niobium, and atomic raw material. Favorable conditions have been established for a considerable expansion of the resources of these metals. Of undoubted interest in this respect are the provinces of Hsinchiang, the northwest portion of inner Mongolia, the central and southern portion of the Shensi province, the western portion of the Hunan province, of the Kwangsi province, Kwangtung, etc.

The Chinese People's Republic is rich in a great variety of complexes of non-metallic useful minerals, the prospected resources of which have increased considerably in recent years.

Of great practical significance are the recently discovered deposits of boron. In the provinces of Kirin and Liaoning there are prospected primary deposits of borates, produced by the contact of limestones with dikes of intrusive rocks. In Playa lakes of Ch'inghai provinces, the presence of boron was established in the brine, and bottom deposits, and in cornolytic [?] deposits. The content of B_2O_3 in the brine reaches more than 4,000 mg/liter. In the bottom silts, and silty sandstones, the boron in quite extensive individual horizons amounts to 2-6 percent. The reserves of boron are apparently quite considerable. In the brine of the lakes is also present potassium and other useful components, which can be extracted at the same time.

In the Chinese People's Republic there are known commercial deposits of phosphorites and apatites, of which the largest ones are located in Yunnan, Szechwan, Kweichow, Anhwei, and Kiangsu. The deposits of phosphorites are predominantly stratified, and belong to the lower Cambrian deposits, with an ore content of 11-15 percent to 25-32 percent P_2O_5. The most promising deposits are in the province of Yunnan, the total reserves of which are estimated to be 500-700 million tons. In addition to phosphorite and apatite, the Chinese People's Republic contains also guano on the islands of Parasel'sk Pratas, and Taiwan.

The main source of sulfur in China is pyrite. Sedimentary pyrite is connected with Jurassic coals and yields more than 80 percent of the quantity extracted in China. The ores are found in the form of lenses and concretions in rocks of the coal series, forming layers with thickness up to one meter. These ores are worked in the provinces of Liaotung, Shansi, Shantung, and Szechwan. In addition, pyrite is being extracted from vein hydrothermal deposits together with copper, lead, zinc, tin, and arsenic in the provinces of Chechiang, Kwangtung and Tsingkai.

In many regions of the Chinese People's

Republic, the investigations of recent years have uncovered rich primary and placer deposits of piezo-optical raw material [Quartz crystal?], part of which is being intensively worked.

Placer deposits of diamonds are known in two regions. The deposits are small in size and the diamonds are of low quality.

In the current year in the province of Szechwan there has been observed a large deposit of high-grade asbestos, the deposits of which according to tentative data, are estimated to be 20 million tons.

The rates of development of geological, as well as in the other braches of the national economy of the Chinese People's Republic, are unprecedented in the world this year as far as the scope of their growth. In searches and prospecting for useful minerals there participated a tremendous mass of the population according to the adopted slogan: "The whole party and the whole nation are engaged in geology." In certain expositions in search of useful minerals, up to 70 percent of the entire population participated. In the district of Tiehhsing in the province of Shansi, 40, 000 locat residents investigated within ten days 20, 000 sections, and disclosed many ore manifestations worthy of attention, a portion of which is already being prospected and exploited.

According to incomplete data, a total of more than 150,000 ore manifestations of various types of mineral raw material were disclosed during the current year, three and a half times more than was observed during the first five year plan.

In 1958 there is a sharp increase in the reserve of the most important useful minerals. If the average annual increase in reserves, reached during the first five year plan, is taken to be 100, the expected increase for 1958 is 800 for iron ore, 600 for tungsten, 2, 000 for aluminum ores, 500 for phosphorites, etc.

In summarizing the work of the All-China Geological Conference, report was made of tremendous experience accumulated by the Chinese geologists during the years of the first five year plan. On the basis of this experience, there are clearly defined the principal trends of search and prospecting operations, and effective methods for their realization are being developed.

There is no doubt that the geological service of China, guided by the general line of the socialist construction: "To strive with all efforts forward, to build more, more rapidly, better, and more economically" will disclose in the nearest years the richest mineral resources and will insure all the branches of the national economy of the country with the necessary raw material.

We wish our friends, the Chinese geologists, all success in this great and noble matter.

OUTLINE OF THE GROUNDWATER IN NORTH CHINA[1]

by

Nobuo Kurata

• translated by Chūzō Kondo •

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VALUE OF THE GROUND WATER AS A RESOURCE

Most of the rivers in North China, including the Huang Ho [Yellow River] which was the "king of tragedy" in the history of China, exhibit special features. Topographically, these rivers are known as "tenjūgawa". [Trans. note: The word "tenjū" means ceiling. These rivers transport an enormous amount of silt from the loess-covered areas and deposit it on the river beds, which are constantly being raised. This necessitates the construction of higher embankments to prevent inundation. Often a tunnel is constructed beneath the river bed to join two towns on opposite sides of the river.] On the river banks there is an extensive distribution of redeposited loess which is similar to "mugikogashi" or parched barley flour. The amount of water that percolates through the soil is so enormous that streams become intermittent or underflow results. This type of river is unusual in Japan. Those who utilize the water must pay particular attention to the seasonal fluctuations of discharge and muddiness of the surface water.

About 60 to 70 percent of the annual rainfall is concentrated in the two months of July and August, and during these months the rivers swell suddenly, usually followed by serious floods. However, with the exception of the rainy season, the amount of river water decreases extremely or is completely absent and a dry condition results. During the dry season there is a considerable fluctuation in the ground water, with a difference in time interval of course. Such a fluctuation can be classified into a high-water period and a low-water period.

The turbidity of the river water is a result of the fine-grained fragile loess that occurs in colloidal suspension, as well as from active erosion because of scanty forests in the drainage basins. According to the survey carried out by the former water Analysis Laboratory of the Railway Technical Research Institute of the North China Traffic Company, the turbidity of the Yung-ting River averages 1, 000^{o} during the high-water season and 600^{o} in the dry season. The [turbidity of the] grand canal [averages] 300^{o} during the high-water season and 150^{o} during the low-water season. However, in the Huang Ho [Yellow River] the maximum is said to be about 12, 000^{o}. Even when such turbid river water is allowed to stand for 6 or 7 hours the majority of the coarse suspended particles are deposited, and in another 24 hours two distinct parts are visible, almost clear water and a deposited layer of mud and minute sand. This experiment shows that when the surface water is utilized it will be necessary to install a filtration pool in which the water can stand for 7 to 8 hours. By putting aluminum sulfate in the water in the pool, water with a turbidity of 700^{o} - 800^{o} can easily be converted into water with a turbidity of only scores of degrees. In 1944 this method was adopted for part of the railway water supply.

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[1]Translated from the Japanese: Geology and Mineral Resources of the Far East, North China, IV - 1b, Ground water, prepared under the auspices of the Compilation Committee of the Geology and Mineral Resources of the Far East, Tokyo Geographical Society, 1951; translation prepared by Engineer Intelligence Division, Office of the Engineer, Hg. U. S. Army Pacific, 1958; edited by Carol Broline, U. S. Geological Survey.

However, on the basis of the geographical distribution of river water, utilization was very limited, so that when a constant large supply was required the ground water had to be utilized. But, the ground water in North China is found in cavities in the Ordovician limestone which forms a part of the basement rock, and as the region is covered by the loess deposit and has an arid climate, not only the agent that forms the ground water varies, but also the quality of the water. Consequently, for those who try to utilize the ground water it is necessary to take special precautions in selecting localities where wells are to be drilled. The ground water drawn from shallow wells located in densely populated villages is very polluted, sometimes has a large chlorine content, and is hard. The quality of this water is quite poor, so is unsuitable not only for drinking and for municipal water supply, but even for industrial uses or for train locomotives. Under such circumstances the general tendency is to look for deep aquifers.

GENERAL FEATURES OF DEEP AQUIFERS[2]

The Japanese managed various installations [in North China] during 1937 - 1945, and the water supply for these installations was drawn from relatively deep-seated aquifers. Water for the municipal water service in the majority of cities, with the exception of part of T'ien-chin, Ch'ing-tao, and Chi-nan, has been supplied by deep, cased wells, and most of the water for locomotives has been supplied by deep, cased wells, with the exception of the areas along the Shih-t'ai and the Chiao-chi railroad where the bedrock is too shallow to drill such deep wells. However, it is fortunate that river water and subsurface flows are available along these railroad lines.

During the years from 1937 to 1944, 800 artesian wells were drilled by the Japanese in the provinces of Ho-pei [Hopeh], Shan-hsi [Shansi], Shan-tung [Shantung], Mongolia, and a part of Ho-nan [Honan], of which 500 were drilled in the North China plain including Ho-pei, Shan-tung, and a part of Ho-nan.

The former Japanese army used 450 wells. The total length of the casing [pipe] was 17,000 m in Ho-pei, 13,000 m in Shan-hsi, and 11, 000 m in Mongolia. The average depth per well was 70 to 80 m in Ho-pei province, 100 to 110 m in Shan-hsi province, and 70 m in Mongolia. Besides these wells, cased wells already existed which had been drilled by Chinese, English, Americans, and French for public organizations, private houses, industrial plants, and municipal waterworks. About 65 of these wells are found in T'ai-yüan, and 15 in Pei-p'ing. There were about 200 artesian or semi-artesian wells (including some bamboo-cased wells drilled by Japanese), of which 7 are in T'ien-chin, about 100 elsewhere, and about 30 in Mongolia (if the nearly abandoned wells are included, the number attains about 60). The aggregate number of wells is about 400. At present the total number of cased wells, which are known through geologic columnar sections or well core samples, may be as large as 1, 000.

All of these wells are called deep wells as the depth of the shallowest aquifer ranges from 20 to 30 meters. Among the wells drilled in the regolith the deepest in 302 m in Te-hsien, and a well drilled in the Ordovician limestone is 550 m deep in Chang-tien. The deepest artesian well was drilled by the French in Lao-hsi-kuan, T'ien-chin, and attained 863 meters.

Table 1 shows the distribution of public wells

TABLE 1. Distribution and uses of deep, cased wells in North China

Cities	Municipal waterworks and the railroad uses	For the Japanese Army	By foreigners other than Japanese
Pei-p'ing	30	10	6
Northern and western suburbs of Pei-p'ing	3	5	4
Tien-chin	7	4	About 100*
Shih-chia-chuan	2	2	-
Chi-nan	-	20 (including core borings)	-
T'ai-yüan	4	25	About 65
Yün-ch'eng and Lin-fen	6	5	-
Te-hsien	2	-	-
Tang-ku	-	5	-
Kai-feng	-	8	-
Ta-tung	-	20 (including core borings)	-
Ch'in-huang-too	-	20	-
Hsing-hsiang	-	6	-
Chang-hsin-t'ien and Liu-li-ho	6	-	-
Lang-fang	-	5	-
Chang-t'ien	4 (including core borings)	-	-

* Including those wells extended by the connection of pipes.

[2] Kurata, Nobuo - The results of searches for and collection of ground water in North China: Water Supply Assoc. Jour. (Suidō Kyōkai Zasshi).

in the principal cities. The wells in the table are only those with data from geologic cross sections.

There are many gushing artersian wells which were drilled into an aquifer with a high hydraulic pressure [literal translation]. Hydrologically, these are very interesting features. Table 2 shows the depth of the aquifers in which the gusher artesian cased wells were drilled.

TABLE 2. Location and depth of aquifers

Location	Depth (meters)	Location	Depth (meters)
Yun-ch'eng	250-290	T'ien-chin	650-690
An-i	200-250	Pao-ti	60 or more?
Pao-t'ou	150	Western suburb of Pei-p'ing	40
Chang-t'ien	260-350		

The temperature of the water in the well drilled in Lao-hsi-kuan, Tien-chin, varies from 31.5° to 34°C, and the average geothermal gradient is 1°C every 30 m. The well yields 400 tons per day.

About a half of the cased wells were drilled by the army portable drilling machine. The time required from completion of a well was about 5 to 6 days in Ho-pei province, 22 days in Shan-hsi province, and 10 days in the Mongolian plateau. About half of the wells range from 100 to 150 m in diameter. The amount of discharge is uncertain because various motive powers have been used; however, a rough estimate is from 600 to 700 tons per day in the North China plain. Some large wells, 250 mm in diameter, in the vicinity of Pei-p'ing yield about 2,000 tons per day. In Shih-chia-chuang, a well discharged 2,800 tons per day and in K'ai-feng one well discharged 4,300 tons per day through a 350 mm pipe.

GENERAL FEATURES OF NATIVE WELLS IN CHINA

In addition to the cased wells, which are known to draw deep-seated ground water, there are many hand-dug open wells which reach shallow aquifers (the first aquifer) and are utilized for various purposes. In most of the North China plain the ground-water level is 2 to 3 m below the surface along the Chin-pu railway and 1 to 8 m along the Ching-han railway.

The populated villages within Hsien-ch'eng (within the prefectural wall) have utilized the water from several to several hundred wells for domestic purposes. Furthermore, such shallow wells have been widely used for farm land irrigation in the neighboring villages. Even within the North China plain, the places where a high density of distribution of shallow wells is found in the mountainous areas of Shan-tung and west of and along the Chin-han railway. It is believed that about 80 to 90 percent of a total of one million wells is distributed in this area. The majority of hand-dug wells for farmland irrigation are shallower than 10 m or vary from 6 to 15 m in depth. Animals, mostly blind horses or donkeys, are used as pumping power for these wells. The [economic] value of the ground water in this arid loess region is high.

However, the natural ground-water level becomes deeper in both the loess tableland and in the loess basin in the Shan-hsi plateau, because to draw the water from the first aquifer excavation to a depth of 30 to 60 m is usually necessary. The deepest hand-dug open well of this type is found on a red clay tableland in Wan-chuan and Jung-ho prefectures in the Chin-nan area [trans. note: south of Shan-hsi province] where artesian wells at the rate of one well for each village, 200 m deep have been an important source of water.

In the Mongolian plateau, on the other hand, the water level is generally high since ground water can be obtained from a depth of 2 - 3 m in the flat land. However, the potable water from these wells is more important for domestic animals than for the Mongolian people. Under such circumstances utilization is very limited, and as a result the degree of pollution is high and the quality of the water is usually very poor.

On the other hand, when the purpose of the well was to draw water from localities where the infiltration of water was possible or along the perennial river banks, shallow wells were dug for the railway, municipal waterworks, and industrial water supplies. One of the most typical examples of this type is found in the waterworks of the Lungyen Iron Foundry in Hsüan-hau where four large wells, about 5 m in diameter, were dug on the floor of the Yang Ho, in the upper reaches of the Yung-ting Ho. The discharge in some of these wells attained as much as 4,000 tons per day. Large shallow reservoirs to collect water at the mouth of the Nan-k'ou-yü, which rises in Pa-ta-ling, have been used mainly for train locomotives at the Ching-pao railway station. The Shih-t'ai and the Chiao-chi railways have also relied on large shallow wells for water supplies.

The discharge from many native wells ranges from 40 to 50 tons per day in the central part of North China and in the coastal region; in the gently-rolling piedmont district the amount varies from 20 to 30 tons per day. In the piedmont the basement rocks project slightly below the plain and the surface soil is extraordinary. This was often the case because in the wells 1 to 1.2 m in diameter, a proper discharge of water was impossible. In the industrial district north of Chi-nan, the aquifers are inadequate for the alcohol factory, despite the group of springs known as the "72 springs of Chi-nan" with a yielding capacity ranging from 14 to 15

tons per day. Under such conditions, large wells were dug with many small strainers placed in radiating form; by doing this a water supply has barely been assured. In the vicinity of Lo-yang, Ho-nan province, there is a tableland consisting of a loamy mud bed resembling hard "yōkan" (a hard bean jelly), and below this bed there is an aquifer known as the San-men gravel. In order to reach this aquifer it was necessary to dig at least 20 m deep, and to assure a proper supply of water large wells were needed. However, some native oval-shaped wells used for irrigation, ranging from 1.8 to 2.5 m in diameter, were already dug. The villages which depended on the ground water used bucket wells [trans. note: the water is obtained by using a bucket] 14 or 15 m in depth, and in places the water was obtained from the aquifer, the water level of which varies from 4 to 5 meters. In the Lu-an basin of Shan-hsi province a thick reddish clayey mud bed extends to a depth of 200 m below the surface without any deep-seated aquifer being discovered. So, in that area a large well was dug into the subsurface flow within the area of the river bed, and by doing this a supply was barely secured for cooling purposes for the power station and for general water supply for the district.

The regolith that occurs in North China can easily be dug by hand because there is no danger of cave in, as is usually the case with gravel beds in Japan. In spite of less trouble in [digging wells in] North China, however, the amount of discharge per well is usually small, so that in order to alleviate this difficulty many wells that had been used for potable water supply were converted into wells to supply water for locomotives by redeepening the native wells by connecting additional pipe. As a result of this method several railway stations east of the Shih-te railway were able to obtain a large amount of good-quality water.

GENERAL FEATURES OF SHALLOW-SEATED GROUND WATER

Ground-water level and its seasonal fluctuations

The ground-water resources in North China and Meng-chiang[3] are not said to be scarce, but water levels in both Shan-hsi and Ho-nan provinces where the loess bed is well developed, especially in the mountain and the plateau districts, are generally very deep, and in order to have access to even an aquifer of the free ground-water table, one must bore to a considerable depth. But in the North China plain and in several basins in Meng-chiang and the Mongolian plateau, the ground water level can be reached at a comparatively shallow depth, and the potable water supplying villages and cities can also be used for farmland irrigation and various other purposes. Table 3 shows the general features of the ground-water levels:

TABLE 3. General features of the ground-water level in Mongolia and Meng-chiang

Locality	Ground-water level (m)
East of Pei-p'ing (North China plain)	4 - 5
Western part of Pei-p'ing	7 - 8
Outside the city of Pei-p'ing	8 - 10
Western suburb of Pei-p'ing	5 - 25
T'ien-chin	2.5
Along the Ping-han railway	4 - 6
Shun-te	6 - 8
Along the Chin-pu railway	2.4
Chi-nan	2 - 30
Hsü-chou	4 - 6
Shan-hsi province	-
T'ai-yüan	5 - 25
Fen Ho valley	6 - 8
Canyon of the Fen Ho at the foot of the mountain	20 - 30
Lu-an	4 - 8
Wan-jung tableland	-
Jung-ho	100
Wu-wang-tu	150
Wan-chüan	220
North of Ho-ching	45 or more
Ho-nan province	-
Lo-yang	20
Meng-chiang and Mongolia	-
Chang-chia-k'ou	4 - 20+
Ta-tung	10 - or more
Pao-t'ou	Shallow in west, deep in east
Mongolian plateau	0.5 - 2

Based on data from -

1. Kurata, N., Nature of inorganic matter in shallow ground water in North China: Japanese Jour. Limnology (Rikusuigaku Zasshi), v. 14.
2. Miyoshi, M., Nature of the irrigation water in North China: Jour. of Sci. of Soil and Manure, Nippon (Nippon Dojō Hirōgaku Zasshi), v. 15.
3. Wada, T., Agriculture of North China based mainly on water: pub. by Seibidō Shoten.

Study of the ground-water levels in 43 cities in North China was begun in 1945 under the direction of Dr. Homma, but the work was forced to be suspended the same year. However, seasonal fluctuation of ground-water levels was observed at Pei-p'ing, Tung-chou,

[3]Ed. Note: Meng-chiang (or Meng-kiang) includes Mongolia and Hsin-chiang (or Hsin-kiang) province in the northwestern part of China where it adjoins Mongolia and Siberia.

western suburb of Pei-p'ing, Ch'ang-hsin-tien, Shih-men (Shih-chia-chuang), Shun-te, Han-tan, Ch'eng-te, Tien-chin, Chi-nan, and Chang-chia-kou. Along the Ching-han railway the highest water level is observed during the months of February and March (high-water season) and during August and September (rainy season), and the lowest water level is seen during July and August (dry season) and in October (low-water season). The highest water level, during February and March, is brought about by a slow but constant increase since the month of November of the preceding year. The maximum increase of ground water along the Chin-han railway is thought to have been brought about by precipitation during the rainy season of the preceding year on the west side of Chi-hsi and T'ai-hsing mountains. The water soaks into the plain and becomes the source of ground water after six or eight months. It is thought that such a seasonal fluctuation of the water levels cannot be seen along the Chin-pu railroad. Going eastward from the west side [of the Chin-pu railway?], the fluctuation of shallow ground water, which is common along the Ching-han railway, seems to decrease.

Three Factors Governing the Quality of the Ground Water

The characteristic feature shown in the quality of the ground water in North China and in a part of Meng-chiang is the high [degree of] hardness due to the high Ca content and SO_4 and Cl contents.

The hardness, especially attributed to the Ca content, ranges from 13° to 30° or 40°, German standard, [231.4 to 534 or 712 ppm] in shallow ground water, and in some extreme cases the hardness attains 120° to 130° [2,136 to 2,314 ppm] or even 150° [2,670 ppm]. Such a high [degree of] hardness is due to the wide distribution of calcareous rocks. The warm and dry climate also accelerated the increase in hardness.

The SO_4 content is also high, generally ranging from 50 to 60 mg/L in good-quality water, but in poor-quality water it ranges from 300 to 400 mg/L. Such a high content is thought to have originated in the presence of coal seams, pyrite beds, and gypsum. In fact, the water seeped into a coal pit where the recorded SO_4 content was often as high as 500 mg/L.

The two above-mentioned examples are thought to be due to natural causes, particularly the quality of the water is closely related to the geology of the area, and $CaSO_4$ has been detected in most cases.

On the other hand, the Cl content has two origins, natural and the artificial. The content of natural Cl is high in former marine formations or in saline areas. Artificial Cl seems to be responsible for pollution.

Characteristic Features of the Water in Saline Districts

The shallow wells in saline regions along the gulf of Po Hai, where the water level is very shallow and the Cl content is too high for the water to be potable for both man and animals. The Cl content is very high and ranges from 2,000 to 3,000 mg/L; however, the SO_4 content is comparatively small. Artesian water in Shan-hsi province, even in the same saline region, has a high SO_4 content and a low Cl content, showing the difference between white alkali and black alkali. The basic principle for the land improvement is required in places where alkaline soil is prominent.

A special characteristic of the water in the saline area of the coastal district is that the content of sodium and potassium is very high. When such water is used in a boiler foam appears. The origin of this phenomenon can be traced to the existence of a former marine formation, and the sodium and potassium contents have been retained to the present due to the prevailing swampy topography. These elements might have dissolved in an earlier stage if the soil was dense and compact, but they have been retained in the ground water because of this topographic condition.

Even though [the water is] somewhat different from that of the coastal saline region, part of a former continental lake (a flood-control reservoir built on the Huang Ho) in Yü-kung is also pointed out as a district of a high Cl content similar to the Pai-yang-tien district. It is an inland saline region but the quality of the water in the district differs considerably. The area along the Lung-hai railway has the best quality water among the poor water areas. In the area where drainage is sluggish the accumulation and concentration of polluted matter is possible, and and an increase in the Cl content in the ground water is noticeable.

Pollution (in populated villages)

The ground water drawn from shallow native wells in villages and cities has usually been polluted from outside sources. The original quality of the water itself has been greatly changed because the Cl content of the original water ranged from 10 to 20 mg/L but became several hundred or even from 2,000 to 3,000 mg/L. The solid matter content is 500 to 1,000 mg/L, and as a result of the presence of Mg the water becomes bitter. Pollution of village water becomes worse toward the center of the village or within the prefectural walls from the periphery, but the degree of pollution decreases in neighboring rivers.

An example from the neighborhood of Ku-an,

Ho-pei province, will be given below. The Cl content of the water from wells in more than ten villages was investigated. For this purpose a tentative boundary was drawn 7 km from the Yung-ting Ho. The investigation revealed that the villages where two-thirds or more of the total number of wells contain more than 100 mg/L of Cl are all located farther than 7 km from the river, and, reversely, the villages where only one-third or less of the total number of wells contain more than 100 mg/L Cl are all situated within less than 7 km from the river.

In the Mongolian plateau, the ground-water level is near the surface. Mongolians treat the wells under unsanitary conditions, and the quality of the water becomes worse and worse. Increase in organic matter and Cl content is notable. For example, within Ta-lun-hsien there are more than 100 shallow wells within the city wall, of which only two or three can be determined to contain potable water when examined on the basis of bacteria and other factors. In Meng-chiang, especially in the Mongolian plateau, the calcium supply is small so the [degree of] hardness is not very high.

Areas Where Comparatively Good Water Supplies Can Be Obtained

Throughout North China the so-called "good water districts" for agricultural uses are situated along the Ching-han railway, between Pei-p'ing, Pao-an, and in the vicinity of T'ai-an along the Ching-p'u railway, where the Cl content is 50 mg/L, hardness is 12^{0} [213.6ppm], and the SO_4 content is 35 mg/L, which should be regarded as the best quality in these districts.

Peip'ing and vicinity is generally considered a "good water district" because the ground water flows from the north and the northwest. But, the southern part of Hsi-cheng, within the city wall, and outside of Ch'ien-men are very poor water areas. However, comparatively good-quality water can be found in newly-developed areas in the southern part of Tung-ch'eng.

The Fe content is especially high in the district outside the city wall. The water from the wells at which water is for sale within the city wall (special wells where water is sold by water merchants), has a Cl content of 100 mg/L and a hardness of 15^{0} [267 ppm]. The Cl content of the water from public wells is 300 mg/L and hardness ranges from 24^{0} to 25^{0} [427 to 445 ppm]. Chi-nan is known as one of the areas with good-quality water as it is the locality of the so-called "seventy-two springs of Chi-nan", which is near the hill on the south side of the city. A good aquifer zone is found there, the water of which has a Cl content of 50 mg/L, but in the city the quality of the water becomes gradually poor. Especially in the low swampy area in the northern and northwestern parts of the city the flow of water become sluggish and the Cl content is 300 mg/L. The Cl content of the spring water within and outside of the city is 12 [mg/L] and the SO_4 content is 40 [mg/L]. In Hei-hu-ch'üan the SO_4 content decreases further, which means the quality is better. Even in the shallow public wells in nearby areas the SO_4 content remains around 30 mg/L.

pH and Temperature of the Water

The pH of the ground water near the surface generally ranges from 7.2 to 7.5. Only part of the Lu-an basin, Shan-hsi province; Chin-tao city, Shan-tung province; near Hai-chou, Chiangsu province; and the area between Ta-tung and K'ou-ch'üan-chen can be determined as having acidic ground water. None of the water is particularly strong alkali. The temperature of the water varies from 12^{0} to 13^{0}C in the winter and from 14^{0} to 15^{0}C in the summer.

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PRINCIPAL TYPES OF HYDROGEOLOGIC STRUCTURES IN THE U.S.S.R.

by

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• *translated by Douglas C. Alverson* •

ABSTRACT

Different parts of the U. S. S. R. are characterized by highly diverse hydrogeologic conditions which permit the distinction of a great number of hydrogeologic regions. The two principal types are artesian basins and hydrogeologic massifs. Artesian basins include platform and intermontane depressions. Hydrogeologic massifs, where fissure-vein ground waters prevail, are found in the crystalline shield areas. The basins and massifs are subdivided into groups depending on conditions of mineralization, temperature, and other specific features of the ground water. Thus, artesian basins are subdivided into those with fresh water, with salt water and brine, thermal waters, and those of permafrost ice. Hydrogeologic massifs include groups with cold carbonate and radon waters, with thermal sulfur-carbonate waters, with cold and thermal methane waters, and with hydrogen-sulfide waters. The distribution of artesian basins and hydrogeologic massifs, and their subgroups, in the U. S. S. R. is given. --M. Russell.

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The problems inherent in subdividing large areas, or even the whole area of the U. S. S. R., into hydrogeologic regions have been examined by many hydrogeologists: M. M. Vasilyevsky, I. K. Zaytsev, N. K. Ignatovich, G. N. Kamensky, O. K. Lange, F. P. Savarensky, A. N. Semikhatov, B. K. Terletsky, N. I. Tolstikhin and others. The different points of view of these investigators will not be presented in this paper, but the system and principles of hydrogeologic classification which were accepted by the Hydrogeology Section of VSEGEI for the compilation of regional hydrogeologic maps of the U. S. S. R., at scales of 1 : 2, 500, 000, 1 : 5, 000, 000 and 1 : 15, 000, 000, will be described briefly. They were developed by the author of this paper and M. P. Paspopov, B. N. Arkhangelsky, M. S. Gurevich, B. B. Mitgarts, E. E. Belyakova and other coworkers in the Hydrogeology Section. This work was carried out in close contact with N. I. Tolstikhin.

The fundamental problem of every scientific classification of natural regions is to establish the laws governing the spatial distribution of those objects and processes, and their associations, with which the given science is concerned. The object of study of hydrogeology is ground water, its formation, quality, quantity, distribution in the depths of the earth, and the means of its utilization. Consequently, a natural hydrogeologic region, in general, is an area on and under the surface characterized by common conditions of formation, recharge, and distribution of ground water of a definite type. It should be emphasized in mapping first-order hydrogeologic regions, that first the predominant type (or types) of ground water should be considered, and secondly, the areas of occurrence and recharge of the ground water should be included, i. e. it should be a basin containing ground water of one type or another. Both requirements are very important. The predominant type of ground water is the concrete expression of the complex and prolonged geologic and hydrogeologic history of this part of the earth's crust; the inclusion of the areas of ground water occurrence and recharge makes calculation of the ground water resources of the basin possible.

In essence then, hydrogeologic mapping should amount to differentiating basins containing ground water of different types that may be considered first-order hydrogeologic regions. Within each first-order hydrogeologic region, areas may be mapped which have aquifer complexes differing in kind, quantity, or other hydrogeologic properties.

Ground water is here subdivided into two principal types; interstitial water occurring in layered rocks, and water occurring fractures and fissures in the rocks. The first type is prevalent in platform regions, piedmont plains and intermontane basins, and the second type is found mostly in folded structures. Ground water regions are classified and designated by the predominant type of ground water.

Platforms are not structurally uniform. Some parts of them have been uplifted and the basement rocks (older folded structures) have been raised, sometimes outcropping at the surface as shields and massifs, and other parts have been downdropped (blocks), and the folded basement covered by a mantle of quietly deposited sedimentary, sometimes extrusive, rocks of various thickness. Intermontane basins occur

[1] Translated from Osnovnyye tipy gidrogeologicheskikh struktur na territorii SSSR: Sovetskaya geologiya, 1959, no. 11, p. 3-15.

in both folded regions and on platforms. In places, folded structures have been downdropped to various depths and covered by relatively quietly deposited rocks of various thickness; other areas have been uplifted, i. e. mountain massifs, which may be considered surface protrusions of the folded structures which form the basements of depressions. Thus, both on platforms and in folded regions, there are two hydrogeologically different structures: 1) downdropped areas of platforms, i. e., basins in which interstitial water in layered rocks is predominant, and 2) uplifted areas, protrusions of the folded basement at the surface, i. e., basins in which ground water occurs mostly in fractures and fissures in the rocks.

Hydrogeologically, it is of great importance whether the area under consideration has been uplifted or downdropped relative to neighboring areas. In an uplifted area, runoff is generally away from the central, more elevated parts and toward the periphery; in downdropped areas, runoff is away from peripheral parts and toward the central, more downdropped part. This has great influence on the formation and zoning of ground water.

Thus, by the nature of tectonic and geomorphic structures, as well as by the direction of runoff and the type of ground water, two types of hydrogeologic structure may be differentiated: 1) artesian basins, in which interstitial water confined under artesian pressure is predominant, and 2) hydrogeologic massifs, in which ground water occurring in fractures and fissures in the rocks is predominant. Hydrogeologic massifs, in turn, are a system of relatively small basins which contain water in fractures and fissures in the rocks as well as in interstitial water not confined under artesian pressure in layered rocks.

In this paper, artesian basins are considered to be those structures, such as troughs, syneclises, depressions, grabens, and similar structures, which have been filled with relatively undisturbed sedimentary rocks in which ground water occurs in the interstices of layered rocks under artesian pressure. Extrusive rocks, such as basalt and trap, which contain water in fractures and fissures, may be present, but generally they have only secondary importance. Basins in which water occurs in fractures and fissures, in karst features, and as other types are found in hydrogeologic massifs. With very rare exceptions, hydrogeologic massifs lock artesian water. It should be mentioned that according to the accepted classification of ground water, not all water under pressure is considered artesian, only water confined in layered rocks under pressure. Consequently, some relatively small intermontane depressions and large river valleys, which do not contain artesian ground water (i. e., water confined in layered rocks under pressure) will not be classified as intermontane artesian basins. These are classified as basins of their respective types of ground water (i. e., basins of ground water in fractures and fissures, basins of ground water in soil interstices, basins of ground water in soil fractures and fissures, etc.). Thus, artesian basins and hydrogeologic massifs are to be found on both platforms and in folded regions. The massifs are always systems of ground-water basins of various types (interstitial soil water, karst-feature water, water in soil fractures and fissures, or all or some types mixed together.

The boundaries between artesian basins on platforms and in folded regions, as well as between large intermontane artesian basins and hydrogeologic massifs of folded regions, occur along the contact of the folded basement at the surface, i. e., in most cases, along the lower slopes of mountain massifs, but not along drainage divides in mountain ranges.

In general, areas recharging all the water-bearing horizons of an artesian basin should be mapped with that basin; consequently, the slopes of mountain ranges which border a basin will sometimes be mapped with that basin.

Extensive platform regions are subdivided into individual large artesian basins, the borders of which pass along hydrogeologic divides, which delimit the ground water runoff into the given basin. Usually such divides coincide with tectonic arches, such as tectonic swells and large anticlines. Artesian basins within platform regions were mapped in this way by M. M. Vasilyevsky in 1937-1939, by the writer in 1939-1945, by N. I. Tolstikhin in 1947-1958, and others.

If the tectonic drainage divides between artesian basins are not sufficiently known, orographic drainage divides may be used. The direction of runoff of ground water, at least in the upper hydrodynamic zones of artesian basins (zones of free and retarded water exchange), is determined by the largest river valleys or by lake basins which drain the artesian basin under consideration.

Artesian basins of platforms and folded regions, similar in geostructural features and predominant type of ground water, may be quite different in degree and type of ground water mineralization, gas content, nature of hydrochemical zoning, geothermal conditions, and other properties. These differences are determined by the geologic structure, physicogeographic conditions, the degree of leaching of soluble salts from the geologic section, etc., that is, by different geologic histories and by different contemporaneous conditions of development. By considering these differences, artesian basins of platforms and folded regions may be subdivided into several types, groups, and

subgroups, which are characterized by more or less identical conditions of formation and distribution of ground water. For clarification of the features which may be used as a basis for classification, it will be necessary, if only in very general terms, to discuss the principles of the formation and distribution of ground water in the above-mentioned structures.

TYPES OF ARTESIAN BASINS

A common feature of all artesian basins is their occurrence in basin-shaped structures or in wide depressions and downwarps, which were marked by prolonged downward movement and the accumulation of thick sequences of stratified sedimentary rocks in the last stages of their formation. In the overwhelming majority of cases, these deposits are relatively undisturbed by faulting and folding, and have generally been deposited quietly on severely deformed, compressed, and metamorphosed basement rocks. Thus, the geologic section in all artesian basins may be divided into two parts.

The upper part (mantle) is composed mainly of quietly deposited sedimentary rocks and forms the artesian basin proper; the lower part consists of severely deformed rocks of various origins, and forms the folded basement of the artesian basin. In artesian basins with a complex geologic structure, several structural stages, each exhibiting a different degree of deformation, may be present in each part of the hydrogeologic section. For example, in the upper part of the Karaganda artesian basin there are two structural stages, the uppermost of which is composed of rocks of Jurassic age, slightly deformed into a basin-shaped structure. The lower structural stage is composed of folded Carboniferous and Devonian deposits, and both stages together comprise one basin, at the base of which are severely deformed and metamorphosed rocks of early Paleozoic age (the folded basement proper).

Some investigators in the Karaganda basin, for example, N. I. Tolstikhin (1937), assign to the mantle only that part of the basin composed of Mesozoic rocks, and consider the Carboniferous and Devonian rocks to be the basement. The problem of what part of a vertical section of a structure should be assigned to the mantle of a given basin, and what part to its basement, may not always be solved identically. The most objective criterion to be followed is the position of the predominant type of ground water, which will be found in some part of the geologic section of the structure. That part of the section in which most water occurs in fractures and fissures in the rocks must obviously be assigned to the basement of the basin, and that part of the section in which the ground water occurs predominantly as interstitial water under artesian pressure in sedimentary rocks is assigned to the mantle. Sedimentary rocks containing water under pressure in fractures and fissures are also assigned to the mantle.

The most typical artesian basins are found on platforms and in large intermontane depressions. The former are termed platform artesian basins, and the latter are called intermontane artesian basins. These basins are different mainly in size, degree of water circulation, and degree of leaching of soluble salts from various parts of the geologic section.

The rocks which comprise the mantle in artesian basins are permeable or impermeable to varying degrees, and form a system of water-bearing horizons or complexes. Hydrodynamic and hydrochemical zoning is clearly shown in cross-sections of most artesian basins. Soil and ground water, which are closely interconnected with the ground surface over the whole area of occurrence, are usually found in the upper part of the section. These waters form a hydrodynamic zone of free water exchange, and are related to atmospheric and surface water such as rivers and lakes. For the most part, these waters have infiltrated down from the surface in relatively recent times. Interstitial water in sedimentary rocks forms a zone of retarded water exchange below the zone of free water exchange. This zone has a limited connection with surface water, mainly at basin margins and along river valleys. In some cases this water is the source of rivers, and in others, river water feeds this zone. Here the water is a mixture of water which has infiltrated from the surface in comparatively recent times and connate water. The more permeable the rocks and the nearer they are to the recharge areas, the greater is the role of infiltrating water from the surface. Still lower in the section is a zone of confined water, which forms a very thick zone (in some regions reaching several thousand meters) of highly retarded water exchange. Water in this zone has hydraulic connection with the ground surface only in some areas of large-scale tectonic ruptures, along which, in some cases, this water is discharged, and in others, surface water infiltrates downward. The connection of this water with water in higher zones is highly restricted, and occurs through the overlying rocks (hydrogeologic windows). The occurrence of ground water in this zone is practically independent of processes occurring at the ground surface at the present time. This water was formed principally in past times by the mixture of water of infiltration, from the surface, with connate water.

In artesian basins, ground-water runoff in the uppermost zones is usually directed away from the marginal, more uplifted parts of the basin, and toward the central parts, or toward the largest and most deeply cut valleys which drain the basin. For this reason, both the

runoff and the ground water regime of these zones is closely related to surface runoff. Ground water of the lowest zone of artesian basins, i. e. in the zone of highly retarded water exchange, does not take part in river runoff, except in rare instances.

The discharge of this water takes place partially along tectonic ruptures and partially through hydrogeologic windows. In artesian basins, ground water of the zone of highly retarded water exchange does move from some parts of the zone into others, and sometimes overflows into neighboring basins, mainly as a result of tectonic movements. It should be remembered that after positive vertical tectonic movements of considerable magnitude, the deepest parts of a basin may be shifted into the zone of intense water exchange.

The hydrodynamic zoning of an artesian basin corresponds to the hydrodynamic features of its different parts, as indicated above. As early as 1937, hydrogeologists have written on this in their reports; this relationship was quite clearly and fully explained in the compilation of the Hydrochemical Map of the U. S. S. R. (1952-1955).

Artesian basins in the U. S. S. R. are classified into several groups and subgroups on the basis of certain features in the formation and occurrence of ground water within them (see map, fig. 1). Brief descriptions of these groups and subgroups are given below.

Group I_1: Artesian basins, in which the principal constituents of the hydrochemical section are brines and saline water, which occupy the lower part of the section to thicknesses of as much as several thousand meters. Brackish and fresh water are found in the upper, less extensive part of the section, with thicknesses of up to several hundred meters. The brines are mostly of sodium chloride, and less commonly of calcium chloride and magnesium chloride, with a high content of bromine, boron, and sometimes potassium, iodine, strontium, radium, lithium and other components. In gas content, the brines are of the nitrogen-methane and methane types, in some places with a high content of hydrogen sulfide. Warm and hot waters occur in the lowermost part of the section.

This group of artesian basins is thus characterized by large supplies of ground-water brines, which may be used as sources of various minerals or for balneological purposes (iodine, bromine, hydrogen sulfide, radium, and other types of water, both cold and thermal). In addition, thermal water may be of interest as a source of natural heat for hothouses, buildings, and other structures.

Many artesian basins on the Russian and Siberian platforms, in Central Asia, and some in Kazakhstan and the Sayan-Altay region belong to Group I_1.

Three subgroups may be differentiated among artesian basins in which brines and saline water are predominant, depending on the thickness and nature of the fresh water zone:

Subgroup I_1^a -- artesian basins, in which fresh water occurs everywhere, forming a zone up to several hundred meters thick in the upper part of the hydrochemical section of the basin.

The Baltic, Pechora, Northern Dvina, Moscow, Volga-Kama, Sura-Khopyor, Dnieper-Donets, Lvov, Karaganda, Kuznets, Minusinsk, Angara-Lena, Tunguska, and Yakutsk artesian basins belong to Subgroup I_1^a. In these basins the zone of fresh water rarely exceeds the range of 150-300 meters in thickness, and only in some parts of the Dnieper-Donets, Lvov, Kuznets, Yakutsk and Tunguska (within the Mesozoic-Cenozoic deposits) basins does it reach 500 or 700 meters. There are considerable quantities of fresh ground water, which may serve as dependable sources for water supplies, everywhere within Subgroup I_1^a.

Subgroup I_1^a -- artesian basins, in which fresh and slightly brackish water are found sporadically, mainly in the upper part of the geologic section, but frequently under more highly mineralized water. The Sarpa, Caspian, Ustyurt, Western Turkmen (Transcaspian), Krasnovodsk-Mangyshlak, Kara-Kum, Teniz-Kurgaldzhin artesian basins belong to this subgroup.

Subgroup I_1^c -- artesian basins, in which fresh water is found mostly as ice in permafrost; liquid fresh water is found only in some parts of taliks, associated with river valleys, lake basins and large tectonic ruptures, or under the permafrost. The thickness of permafrost reaches 200-500 m. The Khatanga, Kotui and Olenek artesian basins, and the northern regions of the Tunguska and Yakutsk basins belong to this subgroup. These basins are all situated in the northern part of the Siberian platform and in its northwest marginal downwarp.

Group I_2: Artesian basins, in which brackish and saline water prevail fresh water has a subordinate importance, and brines are almost unknown in the hydrochemical section. Many basins of Kazakhstan and Siberia belong to this group. Saline and brackish water usually have a mineralization of less than 50-70 grams/liter, and strong brines are found only in some basins in the lowermost part of the sedimentary mantle, although drilling has reached the basement in many places. Brackish, and especially the saline water, are mostly of the sodium chloride

type, but brackish water is also of the sodium bicarbonate and sodium sulfate types, and less commonly of the calcium sulfate type. In deep parts of these artesian basins, water is of the methane-nitrogen, nitrogen-methane, or methane types, by gas content, and ranges from cold to extremely hot and superheated. As stated before, fresh water in this group of artesian basins is quite subordinate. There are several subgroups:

Subgroup I_2^a -- artesian basins, in which fresh water is everywhere present in the upper part of the hydrochemical section, and forms a relatively continuous zone of varying thickness.

The extensive Western Siberian artesian basin belongs to this subgroup. In the southeastern part of this basin (the Ob-Irtysh syneclise) the combined thickness of fresh and brackish ground water zones reaches 1,500-2,000 meters, and in places is thicker than the saline water zone. Warm to extremely hot thermal waters (20° to 90° C), are found in the lower part of the geologic section of this basin. Wells flowing at the surface are common, and are characterized by large yields. These waters may serve as reliable sources of water for agricultural and municipal heating systems, and may also be utilized for balneological purposes.

Subgroup I_2^b -- artesian basins, in which fresh water is encountered sporadically in the hydrochemical section, and forms either small basins under saline water (Aral type) or lies as lenses on saline water. The Turgay basin, the Aral basin group (Donguztau, Chelkar, Chokusu, and others), Syr-Darya, Chu, Ala-Kul-Balkhash, and Zaysan basins belong to this subgroup. The possibility of brines in the lower parts of the sections of these basins is not excluded; their presence could be confirmed by drilling these basins to their basements. The discovery of brines is quite probable in the Chu basin and in some parts of the Syr-Darya basin.

Subgroup I_2^c -- artesian basins having a complex hydrochemical section, including fresh water and brines, alternating and mixed in various sequences. Warm to super-heated thermal water occurs in the lower part of the section; hot water is present at comparatively shallow depths (700-1,500 m). Wells penetrating this water frequently flow at the surface with large discharges. Water of this subgroup may be utilized for heating systems, balneological purposes, and in some cases (superheated waters) can be used to obtain electric power.

Relatively small basins in the south part of the European part of the U. S. S. R., such as the Terek-Kuma, Azov, Black Sea, Kura-Araks, and others as well as basins in the southern part of Central Asia and Kazakhstan -- the Tashkent, Ferghana, Ili, and others, belong to this subgroup. These basins are situated in the marginal parts of folded regions, characterized by youthful tectonic movements, and in some cases by Recent volcanism.

All the artesian basins listed above are rich in fresh water, which can be used for water supply systems, mineral water and balneological purposes. The thermal water can be used for heating systems and as a source of electric power. In some cases the brines contain industrial quantities of iodine, bromine, and other elements.

Group I_3: Artesian basins with predominantly fresh water. Relatively small intermontane basins belong to this group. They are situated in eastern Siberia, in the Far East and northeast, in the mountainous regions of southern Kazakhstan, in the Sayan-Altay, Urals, Caucasus, and other folded regions, but are not shown on the map because of their small size. These basins have been leached of soluble salts to great depths, and fresh water usually is predominant. Brackish or saline water and brines occur at very great depth, in the lowermost part of the section, and are of only secondary importance.

This group of basins is divided into two subgroups:

Subgroup I_3^a -- artesian basins of predominantly fresh water, with brackish or saline water at great depth. The Sakhalin and Kamchatka basins belong to this subgroup. Brackish water occurs at a depth of several hundred meters, and saline water at depths of 1,500 to 2,000 meters. There is no definite information on the geothermal conditions at these depths. However, considering that these basins are situated within youthful folded regions, it may be assumed that thermal waters are present at relatively shallow depths, especially on the Kamchatka peninsula.

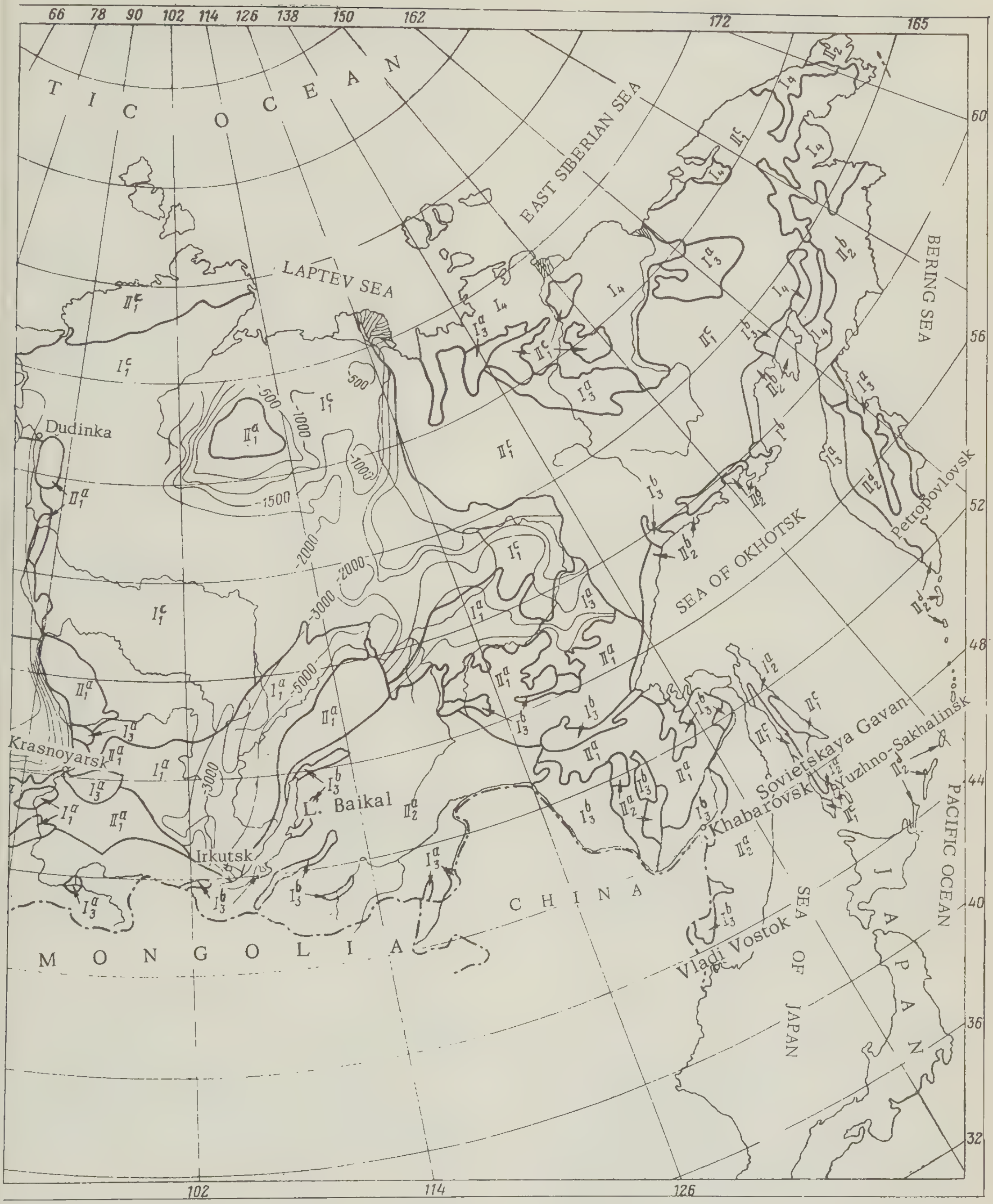
Subgroup I_3^b -- artesian basins of fresh water, in which brackish water may occur at great depth, but brines are absent in the hydrochemical section down to the basement. Most intermontane artesian basins in eastern Siberia and the Far East, such as the Khanka, Bureya, Lower Zeya, Chulman, Baikal, Tunka and Lake Gusinoye basins, belong to this subgroup. Thermal water occurs in the lower part of the section of some of these basins (Tunka, Baikal, and others), beginning at depths of about 1,000 meters.

Group I_4: Artesian basins of extensive ground ice. Fresh water in these basins is frozen to depths measured in hundreds of meters; as a liquid it is found only in rare taliks and under the permafrost. Brackish or saline water, and brines are not known, but they may be present at great depth. The Yana-Indigirka and Penzhina basins are examples of this type of basin.

FIGURE 1. Hydrogeologic

I_1^a - Indices of artesian basins

II_1^a - Indices of folded regions



regions of the U.S.S.R.

-500 - Structural contours on the folded basement in artesian basins (in meters above or below sea level)

- Boundary between different types of hydrogeologic structure

HYDROGEOLOGIC TYPES OF FOLDED REGIONS

A common feature of all folded regions, which permits them to be assigned to a single hydrogeologic classification, is an intensely folded geosynclinal type structure combined with severe metamorphism and a high degree of compaction of all kinds of rocks. In their last stages of formation, some parts of these structures were subjected to prolonged uplift and erosion, and then became hydrogeologic massifs; other parts of these structures were downdropped, with the formation of intermontane artesian basins of various shapes and sizes.

Conforming to the geologic structure of hydrogeologic massifs, the dominant type of ground water occurs in fractures and fissures, and other types are of subordinate significance. Interstitial water does occur rather widely in alluvial, deluvial, and proluvial deposits within the hydrogeologic massifs. Ground water sometimes occurs under artesian pressure in fractures and in rock pores in steeply dipping sedimentary rocks, or basin-shaped structures, forming what are known in the hydrogeologic literature as "artesian slopes", "mountain artesian basins", etc.

In the axial parts of hydrogeologic massifs, which are composed of the oldest metamorphic and igneous rocks, water occurring in fractures and fissures is particularly important. In these areas, the largest amounts of water are present in fractures in strongly metamorphosed sedimentary rocks. In some places, water is available from fractures, fissures, and caverns developed as a result of karst formation. At the foot of the massifs, there is usually a predominance of relatively young and weakly metamorphosed rocks, which contain water in fractures, in places under artesian pressure and forming small artesian basins.

All hydrogeologic massifs are uplifted to some degree relative to adjacent platform or intermontane artesian basins. For this reason, ground and surface water usually runs off from the central parts of the massifs toward the periphery. This is reflected accordingly, in the nature of hydrodynamic and hydrochemical zoning. The intensity of water exchange, and the degree of leaching of soluble salts from rocks decreases away from axial, more uplifted parts, and toward the bases of hydrogeologic massifs. Increased mineralization of ground water, as well as changes in the content of dissolved salts and gases, occur in the same direction. As a result of the considerable erosional dissection of the relief in hydrogeologic massifs, intensive water exchange takes place in thick rock sequences, and the zone of fresh water is commonly measured in many hundreds or thousands of meters. It is especially thick in older hydrogeologic massifs which have been rejuvenated by vertical tectonic movements (as in the Sayan Mountains), and in axial parts of young massifs that are composed either of igneous or older metamorphosed sedimentary rocks (as in the Pamirs). Only in young hydrogeologic massifs, in which halogen-bearing formations (Alpine age) are present in the geologic structure, does fresh water become brackish and saline, and sometimes even brines occur (Carpathians) at relatively shallow depths.

Gold and thermal mineral waters having balneological value, as well as brackish and saline water, are widely distributed in young folded regions. These waters usually flow as springs at the surface, and are associated with large tectonic ruptures. The presence of these springs, and also data from wells, indicate the possibility that there is thermal water, enriched in specific microcomponents and having balneological value, underneath the zone of cold water.

Different mountain massifs and even different parts of the same massif contain dissimilar cold and thermal mineral waters, as a result of complex geochemical conditions which take place at depth. Considering all that has been stated above, folded regions can be subdivided into several groups:

Group II_1: Folded regions, in which cold water occurs predominantly in fractures and fissures, and to a lesser degree under artesian pressure in fractures and as other types of ground water. Thermal water apparently occurs at very great depths. Fresh water with a mineralization of 0.5 to 1.0 gram/liter is most abundant, and is mainly of the oxygen-nitrogen bicarbonate type. In some regions, brackish and saline water occur at depth. Fresh water with a high content of radon, and having a balneological value, is relatively common within crystalline massifs.

Folded regions, formed principally in pre-Paleozoic, Paleozoic, and early Mesozoic time, and in which, since the end of the Mesozoic, there has been little significant tectonic movement of volcanic activity, belong to this group. Folded regions of this group may be divided into several subgroup, according to the degree of leaching of soluble salts, development of permafrost and other features.

Subgroup II_1^a -- folded regions of fresh water, leached of soluble salts to great depth. Brackish and saline water are rarely found, and are present only at great depth. Such folded regions as the Baltic, Ural, Yenisey, Patom-Vitim, Aldan, Dzhagdy, and several others belong to this subgroup.

Island and talik permafrost occur in some of these regions. The folded regions listed above, for the most part, are composed of various older

metamorphic and igneous rocks, in which water occurs mainly in fractures and fissures in the weathering zone, and in fractures and fissures associated with large tectonic ruptures. Other types of ground water are subordinate in these areas. Water occurs in karst fissures and caverns only in the peripheral parts of the Yenisey and Ural folded regions.

Subgroup II_1^b -- folded regions of predominantly fresh water, in which brackish and saline waters occur rather commonly. Strongly eroded folded regions in dry and warm climates, in some places poorly leached of soluble salts, belong to this subgroup. Such regions as the Azov-Podoliya, Donets Ridge, Mugodzhar Mountains, and Central Kazakhstan are assigned to this subgroup.

The Azov-Podoliya folded region is composed of older metamorphic and crystalline rocks, which are covered in large areas by quietly deposited Cenozoic rocks. For the most part, strongly metamorphosed and deformed Paleozoic rocks are present in the geologic structure of other folded regions of this subgroup. In some parts of these regions a relatively clear vertical hydrochemical zoning has been discovered. Brackish and saline water occurs at a depth of several hundred meters. In the Central Kazakhstan region, weak brines were found at depths of 200-300 meters, and deeper, in several small basins composed of Upper Devonian and Lower Carboniferous rocks.

Subgroup II_1^c -- folded regions of continuous permafrost. The thickness of permafrost is measured in hundreds of meters. Fresh water predominates in large tectonic ruptures and under taliks in river valleys and under the permafrost zones. The Anabar, Taimyr, Verkhoyansk, Kolyma, and other similar regions belong to this subgroup. Saline and brackish water, as well as thermal waters, are present only at very great depths in these regions.

Group II_2: Folded regions, where both cold and thermal fresh water occur in fractures and fissures; less commonly brackish and saline water are present. Waters of specific gas content and having balneological significance (nitrogenous, carbon dioxide, hydrogen sulfide, methane, etc.) are widely distributed.

This group is composed mainly of young folded regions, which have been formed principally in the Alpine phase of orogeny, and also of older folded regions, which are characterized by severe youthful (Cenozoic) tectonic movements and volcanism.

According to the character of their thermal and cold mineral waters, these folded regions are divided into several subgroups, which are briefly described below:

Subgroup II_2^a -- folded regions, in which cold carbon dioxide and thermal nitrogenous waters of various chemical composition, but predominantly bicarbonate, and less commonly sulfate, are of widespread occurrence. Tuva, the eastern Transbaikal region, Sikhote-Alin, and other folded regions are in this subgroup.

Within these regions, most water is fresh, and of the oxygen-nitrogen type, occurring in fractures and fissures in the weathering zone and in tectonic rupture zones. Other types of water occur in subordinate amounts. Radon-bearing waters occur rather commonly in the fresh waters of crystalline massifs composed of granite and older metamorphic rocks. Cold carbon dioxide water and thermal nitrogen water are found in the waters of deep-seated tectonic ruptures. The cold waters carrying carbon dioxide are characteristic of folded regions in which tectonic movements of crustal blocks occurred in Cenozoic time. Thermal waters carrying nitrogen are typical of regions where tectonic movements and faulting were accompanied by lava effusions. The carbon dioxide and nitrogen bearing waters may be valuable for balneological purposes, and thermal waters, in addition, may be utilized in heating systems.

Subgroup II_2^b -- folded regions in which thermal brackish and saline chloride waters, carrying nitrogen, are predominant. Included in this subgroup are the folded regions of the Chukot Peninsula, where a large number of thermal springs have been found. Waters in these springs have mineralizations ranging up to 20-30 grams/liter, mostly sodium chloride, and commonly with large amounts of calcium chloride and silica. Cold and poorly mineralized waters of the same type (mineralization up to 1-3 g/L) are found in wells at a number of places on the Chukot coast. Some thermal springs in this region have temperatures of 70-90° C and large yields (up to several tens of liters per second).

Subgroup II_2^c -- folded regions in which both cold and thermal mineral waters of various saline and gas composition (nitrogen, carbon dioxide, hydrogen sulfide, methane, and others), and with various mineralizations (from fresh to brackish and saline) occur widely. In this subgroup are such regions as the Carpathians, the Crimea, and the Caucasus. These are regions which have formed mainly during the Alpine phase of folding or were considerably rejuvenated during this period, as, for example, the Tyan-Shan region. At the present time, the mineral waters of the Caucasus have been studied most intensively (N. N. Slayanov, A. M. Ovchinnikov, F. A. Makarenko, I. M. Buachidze, M. I. Vrublevsky, and others.). In the most uplifted parts of the Great Caucasus, fresh water of the bicarbonate type, carrying oxygen and nitrogen, occurs most widely. However, both cold and thermal waters of various cationic

compositions, carrying carbon dioxide, are commonly found. Below the carbon dioxide bearing water is a belt of both cold and thermal waters carrying nitrogen. At the foot of the mountains and in the depressions is another belt; in the lower part of this belt are methane and sulfur dioxide bearing waters, predominantly of sodium bicarbonate and sodium chloride composition. The Great Caucasus is a hydrogeologic region where both cold and thermal medicinal waters, diverse in salt and gas content (carbon dioxide, nitrogen, hydrogen sulfide, radioactivity, iron, arsenic, and many others) are very widely distributed. Small basins of various types of ground water in the Caucasus commonly have a complex (anomalous) hydrochemical and hydrothermal zoning.

Mineral waters of diverse composition are also known in the Carpathians and in the Tyan-Shan region, but they have been studied much less than the waters of the Caucasus.

Subgroup II_2^d -- folded regions of highly thermal sulfide waters, carrying carbon dioxide, and with a high content of boron, fluorine, and other products of volcanic sublimation. Thermal waters of various chemical compositions are abundant at comparatively shallow depths. The Kamchatka and Kuriles folded regions are in this subgroup. These are regions of young tectonic movements and contemporary volcanism. Mineral waters of these regions have been studied by V. V. Ivanov, O. N. Tolstikhin and others.

In completing this description of the characteristics of the principal types of hydrogeologic regions in the U. S. S. R., it should be noted that even the small amount of data that was given above indicates the specificity of the hydrogeologic conditions of individual regions, which are the result of the mutual activity of a complex of geological and physico-geographic factors in the course of a long geologic history.

In subdividing natural hydrogeologic regions, the contemporary level of hydrogeologic knowledge already has progressed beyond a simple accounting for only fresh ground water, useful for water supply systems. In most of the platform artesian basins and many intermontane basins, fresh water is subordinate to brines or thermal waters in the determination of the hydrogeologic conditions of these regions.

In the practical evaluation of individual hydrogeologic regions, ground water brines and thermal waters have no less significance than fresh water. In some cases they may serve as a basis for the development of health resorts and mineral baths, and in others they may serve as a rich source of various mineral raw materials for chemical industries, and in still others for agricultural and municipal heating systems, and sometimes also for power plants.

In this article only the principal types of hydrogeologic regions have been described. They could be subdivided into still smaller regions, characterized by less diverse complexes of ground water and more specific hydrogeologic conditions. It is possible to map, for example, basins of iodine-bromine waters, boron waters, calcium chloride waters, hydrogen sulfide waters and others, or basins of warm waters, hot waters; degrees of detail not afforded in this presentation.

Review Section

Bardin, I. P. (Editor), THE IRON ORE RESOURCES OF THE FERROUS INDUSTRY OF THE SOVIET UNION. Akademiya Nauk SSR, Moscow, 1957, 556 p., 111 figs. A review by Eugene A. Alexandrov, Columbia University.

This book represents the result of work accomplished by a large group of authors affiliated with the Academy of Sciences, Institutes of the Ministry of Geology, and the Ministry of Ferrous Metallurgy of the Soviet Union. The principal aim of the book is to outline the prospects for the development of iron ore resources of the country during the next 15 to 20 years. There is a definite trend to create strategically independent mining, metallurgical and industrial areas all over the country, especially to the east of the Urals. By 1970 some 60 iron ore deposits will be supplying ore to the industry.

The first two parts of the book aggregate 376 pages dedicated to the genesis of iron ores (editors D. S. Korzhinsky and A. L. Yanshin), a general evaluation of iron ore resources, and to the economic geological characteristics of iron deposits of the Soviet Union (editors M. L. Skobnikov and A. N. Assovsky). The third part of the book deals with possible prospects of utilization of iron ore resources, and was reviewed by Alexander Gakner in United States Bureau of Mines Mineral Trades Notes, vol. 45, nos. 3 and 4, 1957. Therefore, the present review is concerned briefly with the geology of iron ore deposits. A genetical classification of iron ores includes clastic ores, residual ores, sedimentary iron ores in strict sense, Precambrian metamorphic sedimentary iron ores, katogene and infiltration (metasomatic) iron ores, and iron ores of presumably sedimentary or controversial origin. A separate chapter is dedicated to magmatic, contact-metasomatic, and hydrothermal deposits, and conditions of their formation.

The description of individual iron deposits and groups of deposits is arranged on a regional basis. Besides data on the reserves, grade of ore, degree of exploration of each deposit, details of the geologic structure of the deposit are given. This is the most complete and recent compilation on Russian iron ore deposits. In some instances it is illustrated by new maps, reflecting the results of latest discoveries. Descriptions of some of the deposits were never before included in books on Russian iron deposits or mineral resources. However, an economic geologist will find almost no information on the genetic aspects of individual deposits. To some extent this may be compensated for by the first part of the book, dedicated to the general aspects of iron ore genesis.

Academia Sinica, Geological Institute, "Chung-kuo Ta-ti Kou-tsao Kang-yao" OUTLINES OF THE GEOTECTONICS OF CHINA: Science Press of Peking, 320 p., 1959. Review by E. C. T. Chao.

This book is the explanation or text of the Geotectonic map of China at the scale of 1:400,000. The map is not available for inspection.

This book, with many maps, geological cross sections, and columnar sections represents a concerted effort by the Geological Institute of Academia Sinica to consolidate information on the geotectonics and geological history of China into a single volume. In the preface, the compiling institute admits to the inadequacy of the collected data as well as the lack of advanced training of some of the compilers. However, this book gives such an extensive coverage of the geology of China that its review is of general interest to the American geologic public.

The book consists of nine chapters, a preface, a note on its compilation, and an appendix. Chapter I describes the principles used in the subdivision of the tectonic regions or units and defines terms used. The broad tectonic regions are described briefly in Chapter II in terms of the history of development giving the characteristics of each stage of development. This is expanded in Chapter III in a description of structural belts controlled by deep-seated ruptures of basement rock and structures manifested by folding and fracturing of the sedimentary mantle. The first three chapters cover 20 pages of text.

Chapter IV describes the various structural units which are classified into two main categories: those of the platforms or cratons and those of the geosynclinal belts. Altogether there are forty tectonic units belonging to four platforms and geosynclinal belts of Paleozoic, Mesozoic and Cenozoic age. For each unit, the extent, its topographic features, its tectonic classification and subdivision, its history of development and related ore deposits are described. A short bibliography is included at the end of the description of each tectonic unit. Among the references cited are many items published recently in Acta Geologica Sinica and Geological Review (both published in Communist China). Some of the references given are so incomplete as to be useless to American readers. Among the tectonic units are recently surveyed areas and for which information is, for the first time, available to the western world. Such areas include the Chi-lien-shan orthogeosynclinal belt, the K'um-lun-shan

orthogeosynclinal belt, the Nanshan orthogeosynclinal belt, and the Tsaidem massif. This chapter covers 173 pages of text.

Chapter V deals with historical geology. It describes, by geologic age, the sedimentary record, its thickness and variation of lithologic facies. The descriptions are supplemented by a set of eleven isopach maps, at scale of about 1:18,000,000, showing uplifted areas, platform areas, geosynclines and areas of intrusives and extrusives. The isopachs are given with reference to a particular geologic period. Each map is accompanied by a fold-in, generalized columnar correlation chart, some of which show lithologic facies. The coverage of these maps is restricted to areas east of 105° E. longitude.

The history of development of each geotectonic unit is described according to periods of diastrophism in Chapter VI. A set of nine paleotectonic maps, at scale of approximately 1:18,000,000, are included to show areas of transgression, positive land areas and depressions within the land areas. The location of massifs and various geosynclinal and fractured and folded belts and igneous intrusive and extrusive belts is also shown.

Magmatic activities, history and brief description of the igneous rocks for the major tectonic regions are subjects of Chapter VII. The metallogenic provinces are described within the tectonic framework in Chapter VIII. The magmatic activities are described for some fourteen tectonic units including areas of both platform and geosyncline. The metallogenic provinces are described in four sections: 1) endogenic metallic deposits, 2) exogenic deposits of iron, manganese, phosphorous and aluminum, 3) deposits of solid fuel and oil shale and 4) deposits of oil and natural gas. Chapter IX gives a summary of the major tectonic problems.

The compilers of this book include many noted Chinese geologists and a number of Russian geologists serving as consultants or critics: V. M. Sinitsin, N. S. Shatsky, A. L. Yanshin, U. A. Kosikin, P. N. Kropotkin, A. H. Ivanov, M. S. Nagibina, N. M. Neraskov, and U. M. Levinko.

This book is of such scope that anyone interested in the geology of China would find it useful either as background information or in any study of tectonics which includes east Asia.

Reference Section

RUSSIAN AND EAST EUROPEAN GEOLOGIC ACCESSIONS OF THE LIBRARY OF CONGRESS

This section is devoted to a listing of selected geologic items appearing in the two publications of the Library of Congress: Monthly Index of Russian Accessions, and East European Accessions Index. These lists are intended as a means of indicating to researchers in the earth sciences some of the material most recently available for screening, further review, and translation. For this reason the lists do not include material now, or soon to be, published in English. Emphasis is placed on Russian material; the extent to which items from East European sources are listed depends on the country and language involved.

A major function of the AGI translations program is the screening of foreign literature for material that should be made available to the English-speaking scientist. Researchers who need such material are urged to review these lists and send us their recommendations for consideration by the editors; the translation needs of all geologists will be served better thereby.

-- Managing Editor

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- Zaruba, Q.; Lozek, V.; Kukla, J. Early Quaternary sediments in the loam pit of the brickyard near Zalov. p. 225.
- Dudek, A. Problems concerning the Moldanubian shift in the northern part of the Dyje vault. p. 229.
- Pulchart, M. Synthesis of the antimonite monocrystals. p. 233.
- Novak, F. The casserite metallogenesis in the Isergebirge. p. 237.
- Havlicek, V. Report on the results of the revision of the early paleozoic Rhynchonelloidea. in Bohemia. p. 241.
- Havlena, V. Occurrence of variegated beds in the Permocarboniferous areas in Bohemia. p. 245.
- Horny, R. Notes on the correlation of the Bohemian and British Silurian. p. 251.
- Cech, V. Geologicka mapa Ceskoslovenske Republiky - list Pisek (Geologic map of the Czechoslovak Republic; Folio Pisek); a review. p. 255.
- Myslil, V. Congress of the International Association of Hydrogeology (AIH) in Madrid. p. 257.

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INZENYRSKE STAVBY. (Ministerstvo stavebnictvi) Praha. [Journal on structural engineering issued by the Ministry of Building. Superseded, in part, Mechanisace, 1955-56, and Stavebni prumysl, 1955- See also Pozemni stavby and Stavivo. In Jan. 1959 absorbed Mechanisace, which was then converted to a supplement: Mechanizace na inzenyrskych stavbach, on the mechanization of construction and of the manufacture of building materials. Monthly]

Vol. 8, no. 4, Apr. 1960.
- Holcak, B. Lowering of the surface of underground water by the means of pump needles. p. 144.
- Filippov, N. New methods of tunnel draining. p. 150.

Vol. 8, no. 5, May 1960.
- Ralkova, J. Measuring radioactivity in waters. p. 89.

ESTONIA

13. SCIENCE

PERIODICALS

EESTI LOODUS. (Eesti NSV Teaduste Akadeemia) Tartu. [Journal on popular science issued by the Estonian Academy of Sciences; with English and Russian summaries. Bimonthly]
Recurrent feature: Bibliography

No. 1, Jan. 1960.
Orviku, K. Geologic development of Estonia in the Quaternary. I. p. 6.
Masing, V. On the limestone banks of the Don. p. 32.
Jurgenson, E. Interbeds of limestone conglomerate in the Raikula Stage. p. 40.
Paas, A. Notes on the soils of the argillaceous sand district of the Audru River basin. p. 42.
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No. 2, Mar. 1960.
Lookene, E. Geology of the valleys of the Sakala Hill district. p. 72.

HUNGARY

16. TECHNOLOGY

PERIODICALS

Budapest. Femipari Kutato Intezet. A FEMIPARI KUTATO INTEZET KOZLEMENYEI. Budapest. [Papers issued by the Research Institute of the Nonferrous Metals Industry; with English, German, and Russian summaries]
Vol. 3, 1959.
Uveges, J. Evaluation of bauxites on the basis of physical investigations. p. 7.
Mariassy, M. Some new data in connection with the sedimentation of red mud. p. 51.

MELYEPITESTUDOMANYI SZEMLE. (Kozlekedes- es Kozlekedesepitestudomanyi Egyesulet) Budapest. [Publication on civil and construction engineering issued by the Scientific Society of Transportation and Transportation Construction. Monthly]
Vol. 10, no. 6, June 1960.
Egri, Gy.; Rethati, L. Conclusions which could be drawn from measuring sinkings. p. 257.
Vastagh, G. Lessons and guiding principles of the construction of earth dams on the basis of American experiences. Pt. 1. (To be contd.) p. 264.
Sarosi, L. Construction of earth dams in Czechoslovakia. p. 271.

MUSZAKI ELET. (Muszaki es Termeszettudomanyos Egyesuletek Szovetsege) Budapest. [Publication on technology and production issued by the Federation of Technical and Scientific Associations. Title varies: before v. 10, 1955, Magyar Technika. Semimonthly]
Vol. 15, no. 11, May 1960.

Vol. 15, no. 12, June 1960.
Hedervari, P. Earthquakes and forecasting earthquakes. p. 5.
Problems which can be solved; geologic research. p. 2.

LITHUANIA

16. TECHNOLOGY

PERIODICALS

Kaunas. Politechnikos institutas. DARBAI. TRUDY. Kaunas. [Papers on technical science issued by the Kaunas Polytechnic Institute. In Lithuanian or Russian with a summary in the language different from that of the articla]

Vol. 9, 1958.
Simkus, J. Resistance of foundations made by morainal argillaceous soil. p. 55.
Tamasevicius, A. Elevation of a roadbed crown over the level of soil waters under the conditions of the Lithuanian SSR. p. 67.
Martisius, A. Problem of distributing reactive soil pressures under a rigid square foundation. p. 77.

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12. GEOGRAPHY & GEOLOGY

STESLICKA, WANDA. Homo sapiens fossilis z Siemonii. Profil osadow dyluwialnych z Siemonii opracowal Anatol Zielinski. Wroclaw, 1960. 57 p. (Polska Akademia Nauk. Zaklad Antropologii. Materialy i prace antropologiczne, nr. 48) [Homo sapiens fossilis of Siemonia. A. Zielinski: A profile of the diluvial deposits of Siemonia. French summary. illus., maps, bibl., footnotes, graphs, tables]

PERIODICALS

ACTA GEOLOGICA POLONICA. (Polska Akademia Nauk. Komitet Geologiczny) Warszawa. [Journal issued by the Committee on Geology, Polish Academy of Sciences; with English, French, and Russian summaries. Superseded in part by Acta Paleontologica Polonica, 1956. Quarterly]
Vol. 9, no. 4, 1959.
Konior, K. The character and age of intrusions of magmatic rocks of Teschen Silesia. p. 445.
Birkenmajer, K. The Czertezik series, a new Klippen series in the Pieniny Mountains. p. 499.
Kotanski, Z.; Radwanski, A. The High Tatra Tithonian of the Osobita region, its limburgites, and Pygope diphya.
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Oberc, J. The tectonics of eastern Riesengebirge and their position in the structure of the Sudeten. p. 1.
Dumicz, M. Observations of minor tectonic structures in the southern part of the metamorphic formations of the Habelschwerdt Mountains. p. 49.
Don, B.; Don, J. Origin of the Neisse graben against the background of the geological survey in the vicinity of Idzikow. p. 71.

GEOLOGIA. (Akademia Gorniczo-Hutnicza w Krakowie) Krakow. [Papers on geology issued by the Academy of Mining and Metallurgy in Krakow; with English and Russian summaries]
No. 3, 1959.
Stopa, S. A new presentation of anticlinal deposits; a group of Zabrze deposits belonging to Namur B. p. 3.
Trembecki, A. An analysis of the rock-cracking in frequency determining the index of quantity of building blocks from a quarry. p. 23.
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Mochnacka, K. Hydrothermal alterations in the tin-bearing mica schists of the Gierczyn mine in the light of recent theories on the chloritization of rocks. p. 81.

16. TECHNOLOGY

NAFTA. (Instytut Naftowy) Krakow. [Journal on petroleum engineering, processing, and management issued by the Petroleum Institute. Includes supplements: Przeglad Dokumentacyjny Nafty, documentation; Wiadomosci Naftowe, information bulletin; and Biuletyn Instytutu Naftowego, bulletin of the Institute. Monthly]
Recurrent feature: Information from the Institute.

Vol. 16, no. 1, Jan. 1960.
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Vol. 16, no. 5, May 1960.
Obuchowicz, Z. The scope and results of petroleum prospecting in the years 1957-1959, and directives for raising its effectiveness. p. 121.

PRZEGLAD GEOLOGICZNY. (Wydawnictwa Geologiczne) Warszawa. [Publication on economic geology issued by Geologic Publications. Monthly] Recurrent features: Organizational and legal problems; Brief notes; New publications; reviews and foreign periodicals; Standards and instructions.

Vol. 7, no. 12, Dec. 1959.
Grzybowski, J. Remarks on the Lower Silesian deposits of kaolin and their utilization for industrial purposes. p. 533.
Uberna, J. Kaolin and quartz veins in the region of Wadroze Wielkie. p. 536.
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ROZPRAWY HYDROTECHNICZNE. (Polska Akademia Nauk. Instytut Budownictwa Wodnego) Warszawa. [Research papers on hydraulic engineering issued by the Institute of Hydraulic Construction, Polish Academy of Sciences; with English and Russian summaries]

No. 6, 1959.
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Academia Republicii Populare Romine. Institutul de Geologie si Geografie. STUDII SI CERCETARI DE GEOLOGIE. Bucuresti. [Journal on geology issued by the Institute of Geology and Geography, Rumanian Academy; with French and Russian summaries. Superseded in part, in 1958, and continues the vol. numbering of Academia Republicii Populare Romine. Buletin stiintific. Sectia de geologie si geografie, which superseded in part, in 1956, Academia Republicii Populare Romine. Sectiunea de Stiinte Biologice, Agronomice, Geologice si Geografice. Buletin stiintific, issued before 1951 as Academia Republicii Populare Romine. Buletin stiintific. Seria: Geologie, geografie, biologie, stiinte tehnice si agricole. See also Academia Republicii Populare Romine. Buletin stiintific. Sectia de biologie si stiinte agricole. Seria agronomie, Academia Republicii Populare Romine. Studii si cercetari de biologie. Seria biologie animala, and Academia Republicii Populare Romine. Studii si cercetari de biologie. Seria biologie vegetala. Quarterly]

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At the 15th anniversary of Rumania's liberation. p. 191.
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Petrulian, N.; Steclaci, L.; Oroveanu, F. A study of hypergene minerals from the polymetallic deposit Tomnatec-Tibles and obtaining them by experimental methods. p. 207.
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Krautner, H. Criteria for the classification of serpentine minerals by means of thermal differential analysis. p. 281.

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Academia Republicii Populare Romine. Filiala Iasi. STUDII SI CERCETARI STIINTIFICE. FIZICA SI STIINTE TEHNICE. Iasi. [Journal on physics and technical sciences issued by the Iasi Branch, Rumanian Academy; with French and Russian summaries. Superseded in part, in 1956, and continues the vol. numbering of its Studii si cercetari stiintifice. Seria I: Stiinte matematice, fizice, chimice si tehnice, which superseded in part its Studii si cercetari stiintifice, July 1954. See also its Studii si cercetari stiintifice. Chimie and its Studii si cercetari stiintifice. Matematica]
Vol. 10, no. 2, 1959.

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Vol. 4, no. 4, 1959.
Bolgiu, O. The utilization in scientific research of certain electric properties of matter, unregistered until now. p. 477.
Mantea, S.; Petrescu, M.; Trita, V. A method for spectrographic determination of germanium in mineral coal. p. 537.
Mantea, S.; Petrescu, N.; Petrescu, M. The presence of germanium in some Rumanian coals and lignites. p. 547.
Bolgiu, O.; Dumitrescu, A. Observations on the dilation of quartz. p. 587.
Bolgiu, O.; Fruchter, S. On certain properties of limestone in connection with their use in siderurgy. p. 393.
Academia Republicii Populare Romine. Centrul de Cercetari Metalurgice. STUDII SI CERCETARI DE METALURGIE. Bucuresti. [Journal issued by the Center of Metallurgic Research, Rumanian Academy; with French and Russian summaries. Superseded in part Studii si cercetari de mecanica si metalurgie, 1956. See also Academia Republicii Populare Romine. Institutul de Mecanica Aplicata. Studii si cercetari de mecanica aplicata]
Recurrent feature: Book reviews.
REVISTA MINELOR. (Ministerul Minelor, Ministerul Industriei Petrolului si Chimiei, Directia Exploatarilor Miniere si Asociatia Stiintifica a Inginerilor si Tehnicienilor din Rominia) Bucuresti. [Publication on mining and related industries issued by the Ministry of Mines, the Ministry of the Petroleum and Chemical Industries, the Direction of Mine Operation, and the Scientific Association of Engineers and Technicians of Rumania; with Russian summaries. Monthly]
Recurrent features: Standardization; Book reviews; Correspondence with readers.

Vol. 11, no. 4, Apr. 1960.
Lupei, N. New hypotheses in carrying out geologic research for ore in the auriferous quadrilateral. p. 162.

YUGOSLAVIA

12. GEOGRAPHY & GEOLOGY

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Belgrade. Seizmoloski zavod. BULLETIN SEISMIQUE MENSUEL. Beograd. [Bulletin issued by the Seismologic Institute in Belgrade. In French. Title varies: before 1954, its Enregistrations Seismographiques. Monthly]
Jan., May 1960.

GEOGRAFSKI VESTNIK. (Geografsko drustvo v Ljubljani) Ljubljana. [Annals on geography and related sciences issued by the Geographical Society in Ljubljana; with English and French summaries]
Recurrent features: Book reviews; Survey of periodicals.
Vol. 31, 1959.
Oblak, P. Jelovica; chapters from natural geography. p. 3.
Oblak-Polajnar, M. The valley of Logatec as a geographical individuality. p. 19.
Vriser, I. Origin and development of Nova Gorica; geography of a rising city. p. 45.
Gams, I. Problems of the regional delimitation of Dolenjska and Bela Krajina. p. 79.

Ramovs, A. Paleozoic and Mesozoic rocks in the dislocation zone of Donacka gora. p. 97.
Furlan, D. Advancement of Central European singularities on the territory of Yugoslavia. p. 121.
Manohin, V. Origin and preservation of glaciers in the mountains. p. 131.
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Ilesic, S. New contributions to the study of the geography and history of agrarian regions. p. 158.
Bernot, F. Fifth International Congress of Alpine Meteorologists in Garmisch-Partenkirchen, September 14-16, 1958. p. 166.
Kokole, V. Anton Melik's Jugoslavija Zemljepisni pregled. 3. predelana in razsirjena izd. (Yugoslavia; a Geographical Survey. 3d rev. and enl. ed.); a book review. p. 169.
Kokole, V. Jugoslavija-turisticka enciklopedija. Knj. I, II. (Yugoslavia; a Tourist Encyclopedia. Vols. 1-2); a review. p. 170.
Gams, I. New regional symposiums; a book review. p. 171.
Rakovec, S. Ivan Mohoric's Zgodovina obrti in industrije v Trzicu (History of Handicraft and Industry in Trzic); a book review. p. 174.
Vriser, I. Janko Orozen's Zgodovina Trbovelj, Hrastnika in Dola. I (History of Trbovlje, Hrastnik, and Dol. Vol. 1.); a book review. p. 177.
Trifunoski, J. Branislav Bukurov's Poreklo stanovnistva Vojvodine (Origin of the Population of Vojvodina); a book review. p. 179.
Trifunoski, J. Mark Krasnici's Orahovac, antropogeografska monografija varosice (Orahovac, an Anthropogeographical Monograph of the Town); a review. p. 180.
Ilesic, S. Nase jame, v. 1, no. 1, 1959; a review of a periodical. p. 182.
Gams, I. Dr. Franc Jenko's Hidrogeologija in vodno gospodarstvo krasa (Hydrogeology and Water Economy of Karst); a book review. p. 183.
Gams, I. Savezno savetovanje o krsu. I. Krs Slovenije. II. Krs Hrvatske. III. Krs Bosne in Hercegovine. IV. Krs Crne Gore. V. Krs Jugoslavije (Federal Conference on Karst. Vol. 1. Karst of Slovenia. Vol. 2. Karst of Croatia. Vol. 3. Karst of Bosnia and Hercegovina. Vol. 4. Karst of Montenegro. Vol. 5. Karst of Yugoslavia); a review of books. p. 185.
Gams, I. Krs Jugoslavije I. (Karst of Yugoslavia. Vol. 1); a book review. p. 188.
Gams, I. Karst in the publications of international congresses. p. 189.
Ilesic, S. Mieczyslav Klimaszewski's "New Ideas Concerning the Development of Karst Morphology"; a review of an article. p. 194.
Furlan, D. Letno porocilo Hidrometeoroloskega zavoda LRS v Ljubljani, 1953 (Annual Report of the Hydrometeorological Institute of Slovenia in Ljubljana, 1953); a book review. p. 196.
Ilesic, S. Meteoroloski zbornik. I. snop. (Meteorological Symposium. Vol. 1.); a book review. p. 197.
Ramovs, A. Geology in Geografski vestnik, no. 27/28, 1955/56; a review of a periodical. p. 204.

13. SCIENCE

PERIODICALS

CROATICA CHEMICA ACTA. (Hrvatsko kemijsko drustvo, Sveuciliste u Zagrebu i Hrvatsko prirodoslovno

drustvo) Zagreb. [Journal issued by the Croatian Chemical Society, the University of Zagreb, and the Croatian Society of Natural Sciences. In English, German, Serbo-Croatian, and Slovenian with summaries in a language different from that of the article. Title varies: before v. 28, 1956, Arhiv za kemiju. Quarterly]

Recurrent features: Book reviews; Bibliography.

Vol. 31, no. 4, 1959.

Miholic, S.; Stancic, B. Thermal spring in Lasko; geochemical study. p. 149.

GEODETSKI LIST. (Drustvo geodeta Hrvatske) Zagreb. [Journal issued by the Society of Geodesists of Croatia. Monthly]

Recurrent feature: Review of domestic and foreign periodicals.

Vol. 14, no. 4/6, Apr./June 1960.

Boaga, G. Deviation of the vertical and the shape of geoids in Italy. p. 117.

BILTEN DOKUMENTACIJE. RUDARSTVO I GEOLOGIJA. BULLETIN OF DOCUMENTATION. MINING AND GEOLOGY. (Jugoslovenski centar za tehnicku i naucnu dokumentaciju) Beograd. [Abstracts from domestic and foreign periodicals, patents, and standards issued by the Yugoslav Center for Technical and Scientific Documentation. Superseded in part, in 1957, and continues the vol. numbering of Bilten dokumentacije za rudarstvo, metalurgiju i geologiju, which superseded in part Bilten; dokumentacija strucne literature, 1955. See also Bilten dokumentacije. Goriva i maziva and Bilten dokumentacije. Metalurgija. Monthly]

Vol. 11, no. 5, May 1960.

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In this index, the following words have been dropped wherever they occur as first words of a title: the, a, an, of, on. Except for title listings, the following also have been dropped: study of, problem of, experiment in, results of. The first word of the pertinent title is usually capitalized, although in some subject entries, the reference may note only those words of the title needed to indicate scope of the article, in which cases only proper nouns are capitalized. Japanese and Chinese authors are given western style, with family name last.